A

TEXT-BOOK

OF

GEOLOGY.

DESIGNED FOR SCHOOLS AND ACADEMIES.

BY

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PREFACE.

In preparing this abridgment of my Manual of Geology, the arrangement of the larger work has been retained. The science is not made a dry account of rocks and their fossils, but a history of the earth's continents, seas, strata, mountains, climates, and living races; and this history is illustrated, as far as the case admits, by means of American facts, without, however, overlooking those of other continents, and especially of Great Britain and Europe.

No glossary of scientific terms has been inserted, because the volume is throughout a glossary, or a book of explanations of such terms, and it is only necessary to refer to the Index to find where the explanations are given.

The teacher of Geology, and the student who would extend his inquiries beyond his study or recitation-room, is referred to the "Manual" for fuller explanations of all points that come under discussion in the "Text-book,—including a more complete survey of the rock-formations of America and other parts of the world, with many sections and details of local geology,—a much more copious exhibition of the ancient life of the several epochs and periods and of the principles deduced from the succession of living species on the globe,—a more thorough elucidation of the departments of Physiographic and Dynamical Geology,—a chapter on the Mosaic Cosmogony,—and a large number of additional wood-cut illustrations, besides a general chart of the world.

New Haven, Ct., December 1, 1863.

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INTRODUCTION.

1. **Rock-structure of the earth's crust.**—Beneath the soil and waters of the earth's surface there is everywhere a basement of rocks. The rocky bluffs forming the sides of many valleys, the ledges about the tops of hills and mountains, and the cliffs along sea-shores, are portions of this basement exposed to view.

The rocks generally lie in beds; and these beds vary from a few feet to hundreds of yards in thickness. The different kinds are spread out one over another, in many alternations. Sometimes they are in horizontal layers; but very often they are inclined, as if they had been pushed or thrown out of their original position; and in some regions they are crystallized. Moreover, they are not all found in any one country.

By careful study of the rocks of different continents, it has been ascertained that the series of beds, if all were in one pile, would have a thickness of 15 or 18 miles. The actual thickness in most regions is far less than this.

These 15 or 18 miles out of the 4000 miles between the earth's surface and centre are all of the great sphere that are within reach of observation.

The series of rocks alluded to overlie, beyond all question, crystalline rocks that are not part of the series. There is good reason for believing, also, that, not many scores of miles below the surface, the whole interior of the globe is in a melted state. These fiery depths are nowhere open to examination; yet the rocks ejected in a melted state from volcanoes or from the earth's fissures are supposed to afford indications of what they contain.

2. **Facts taught by the arrangement and structure of the rocks.**—The various rocks afford proof that they were all slowly or gradually made,—the *lowest* in the series, of course, first, and so on upward to the last. The lowest, therefore, belong to an early period of the world, and those above to later periods, in succession.

Some of the beds indicate, by evidence that cannot be doubted, that they were made over the bottom of a shallow ocean, like the muddy and sandy deposits on soundings; or along the ocean's borders, like the accumulations of a beach, or of a salt-marsh; others, that they were formed by the action of the waters of lakes, or of rivers; and others still, that they were gathered together by the drifting of the winds, as sands are drifted and heaped up near various sea-coasts. In many of the rocks there are marks on the layers that were made by the rippling waves or the currents when the material of the bed was loose sand or clay; or there are cracks—though now filled—that were opened by the drying sun in an exposed mud-flat; or impressions produced by the drops of a fall of rain.

In some regions the beds, after being consolidated, have been profoundly fractured, and the fissures thus opened were often filled at once with rock, in a melted state, proceeding from the depths below. Again, they have been uplifted or pressed into great folds, and mountain-ranges have sometimes been made as a consequence of the upturning; and, in addition, they have often undergone crystallization over a country thousands or even hundreds of thousands of square miles in area.

The succession of rocks in the earth's crust is, hence, like a series of historical volumes, and full of inscriptions. It is the endeavor of Geology to examine and interpret these inscriptions. They are sufficient, if faithfully studied and compared, to make known the general condition of the continents and seas in the course of the world's progress, and also to tell of the epochs of disturbance or revolution, and of mountain-making.

3. **Facts taught by the fossil contents of rocks.**—Again, most of the beds contain shells, corals, and other related forms, called *fossils*,—so named because *dug out* of the earth, the word being from the Latin *fossilis*, meaning, *that which is dug up*. These fossils are the remains of living animals that once inhabited the earth. The shells and corals were formed by animals, just as the shell of a clam is now formed by the animal occupying it, or corals of existing seas by the coral animals. The various species that have left their remains in any bed must have been in existence when that bed was in progress of formation: they were the living species of the waters and land at the time.

The fossils that occur in one bed differ in species entirely, or nearly so, from those of every other bed in the series. In other words, each bed has its own peculiar species, those of the bottom almost or wholly unlike those in the one next above; and those of this bed as much unlike those of the following; and so on. Since, therefore, each bed contains evidence as to what animals and plants were living when it was forming, the study of the fossils of the successive beds is the study of the succession of living species that have existed in the earth's history.

4. **Objects of Geology, and Subdivisions of the science.**—The preceding explanations afford an idea of the objects of the science of Geology. They are—

(1.) To study out the system in the earth's features.

(2.) To ascertain the nature and arrangement of the rocks.

(3.) To make out the true history, or succession of events, as to the formation of rocks, the production of the features of the surface and the disturbances of rocks, and the progress and all changes in the living species of the globe.

(4.) To determine the causes of all that has happened in the earth's history, that it may be understood how rocks were made, fractured, uplifted, folded, and crystallized; how mountains were made, and valleys, and rivers; how continents and oceanic basins were made, and how altered in size or outline from period to period; why the climate of the globe changed from time to time; and how the living species of the globe were exterminated, or otherwise affected by the physical changes in progress.

There are, hence, *four* principal branches of the science:—

1. Physiographic Geology,—treating of the earth's physical features; that is, of the system in the exterior features of the earth. (This department properly includes, also, the system of movements in the water and atmosphere, and the system in the earth's climates, and in the other physical agencies or conditions of the sphere.)

2. Lithological Geology,—treating of the rocks of the globe, their kinds, structure, and conditions or modes of occurrence. The word *lithological* is from the Greek *lithos*, *stone*, and *logos*, *discourse*.

3. Historical Geology,—treating of the succession in the rocks of the globe, and their teachings with regard to the successive conditions of the earth, or to the changes in its oceans, continents, climates, and life.

4. Dynamical Geology,—treating of the causes, or the methods, by which the rocks were made, and by which all the earth's changes were brought about. The word *dynamical* is from the Greek *dunamis*, *power* or *force*.

These causes have acted through the sustaining power and guidance of the great Cause of causes, the Infinite Creator, who made matter and all the kinds of life, and who has ever directed and still directs in every passing event.

PART I.

PHYSIOGRAPHIC GEOLOGY.

UNDER the department of Physiographic Geology only a brief and partial review is here made of the general features of the earth's surface.

THE EARTH'S FEATURES.

1. GENERAL CHARACTERISTICS.

1. *Size and form.*—The earth has a circumference of about 25,000 miles. Its form is that of a sphere flattened at the poles, the equatorial diameter (7926 miles) being about 13¼ miles greater than the polar.

2. *Oceanic basin and continental plateaus.*—Nearly *three-fourths* (more accurately, *eight-elevenths*) of the whole surface are depressed below the rest and occupied by salt water. This sunken part of the crust is called the *oceanic basin*, and the large areas of land between, the *continents*, or *continental plateaus.*

3. *Subdivisions and relative positions of the oceanic basin and continental plateaus.*—Nearly *three-fourths* of the area of the continental plateaus are situated in the northern hemisphere, and more than *three-fourths* of the oceanic basin in the southern hemisphere. The dry land may be said to be clustered about the North pole, and to stretch southward in *two* masses, an *Oriental*, including Europe, Asia, Africa, and Australasia, and an *Occidental*, including North and

South America. The ocean is gathered in a similar manner about the South pole, and extends northward in *two* broad areas separating the Occident and Orient, namely, the Atlantic and Pacific Oceans, and also in a *third*, the Indian Ocean, separating the *southern prolongations* of the Orient, namely, Africa and Australasia.

The Orient is made, by this means, to have *two* southern prolongations, while the Occident, or America, has but one. This double feature of the Orient accords with its great breadth; for it averages 6000 miles from east to west, which is far *more than twice* the breadth of the Occident (2200 miles).

The inequality of the two continental masses has its parallel in the inequality of the Pacific and Atlantic Oceans; for the former (6000 miles broad) is more than double the average breadth of the latter (2800 miles). Thus *there is one broad and one narrow continental mass*, and *one broad and one narrow oceanic area.*

The connection of Asia with Australia, through the intervening islands, is very similar to that of North America with South America. The southern continent, in each case, lies almost wholly to the *east* of the meridians of the northern; and the islands between are nearly in corresponding positions,—Florida in the Occident corresponding to Malacca in the Orient, Cuba to Sumatra, Porto Rico to Java, and the more eastern Antilles to Celebes and other adjoining islands. It is, therefore, plain that Australia bears the same relation to Asia that South America does to North America. It is also true that Africa is essentially in a similar position with reference to Europe.

The northern portion of the Orient, or Europe and Asia combined, makes one continental area; and its general course is *east and west.* The northern portion of the Occident, or North America, is elongated from *north to south.*

4. *Oceanic depression and continental elevations.*—The depth of the oceanic basins below the water-level is probably in

some parts 50,000 feet. The mean depth is much less. The depth across from Newfoundland to Ireland, along what is called the telegraphic plateau, is from 10,000 to 15,000 feet. Farther south, the Atlantic Ocean is undoubtedly very much deeper; but the soundings hitherto made are not trustworthy as to the exact depth. The mean depth of the north Pacific between Japan and San Francisco has been determined by Professor Bache, from the passage of earthquake-waves in 1855, to be 13,000 feet. This is the narrower part of the Pacific Ocean, and is probably much less deep than that in the southern hemisphere.

The highest point of the continents that has been measured is 29,000 feet: it is the peak called Mount Everest, in the Himalayas. But the mean height of the continental plateaus is only about 1000 feet. The mean height of the several continents has been estimated as follows: Of Europe, 670 feet; Asia, 1150 feet; North America, 748 feet; South America, 1132 feet; all America, 932 feet; Europe and Asia, 1000 feet; Africa, probably 1600 feet; and Australia, perhaps 500. The material in the Pyrenees, if spread equally over Europe, would raise the surface only 6 feet; and that of the Alps, only 22 feet. Although some mountain-chains reach to a great elevation, their breadth above a height of 1000 feet is small compared with that of the continents below this height.

5. *True outline of the oceanic depression.*—Along the oceanic borders the sea is often, for a long distance out, quite shallow, because the continental lands continue on under water with a nearly level surface; then comes a rather sudden slope to the deep bed of the ocean. This is the case off the eastern coast of the United States, south of New England. Off New Jersey, the deep water begins along a line about 80 miles from the shore; off Virginia, this line is 50 to 60 miles at sea; and thus it gradually approaches the coast to the southward. The slope of the bottom for the 80 miles

off New Jersey is only 1 foot in 700 feet. The true boundary between the continental plateau and the oceanic depression is the commencement of the abrupt slope. The British Islands are situated on a submerged portion of the European continent, and are essentially a part of that continent, the limit of the oceanic basin being far outside of Ireland, and extending south into the Bay of Biscay. New Guinea is in a similar way proved to be a part of Australia.

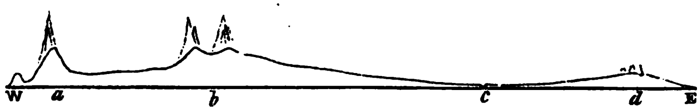
6. *Surfaces of the continents.*—The surface of a continent comprises (1) *low lands*, (2) *high* or *elevated plateaus* or *table-lands*, and (3) *mountain-ridges*. The mountain-ridges may rise either from the low lands or the plateaus. The *plateaus* are great areas of the surface situated several hundred feet, or a thousand feet or more, above the sea, or above the general level of the low lands. They are often a part of the great mountain-chains. Sometimes plateaus include a region between mountain-ridges, and sometimes the mass of the mountains themselves out of which the ridges rise. For example, the regions of northern and southern New York are plateaus (the former averaging 1500 feet in height, the latter 2000 feet) situated within, or on the borders of, the Appalachian chain. The eastern part of New Mexico is a plateau about 4000 feet above the sea, called the Llano estacado, and Mexico is situated in another plateau, from which rise various ridges and peaks; and both of these, besides others, are situated in the region of the Rocky Mountain chain, or the great western chain of North America. The Desert of Gobi, between the Altai and the Kuen-Luen range, is a desert plateau about 4000 feet high. Persia and Armenia constitute another plateau. These examples are sufficient to explain the use of the term.

2. System in the Earth's Features.

1. *General form of the continents resulting from their reliefs.*—The continents are constructed on a common model, as

follows: *they have high borders and a low centre, and are, therefore, basin-shaped.* Thus, North America has the Appalachians on the eastern border, the Rocky chain on the west, and between these the low Mississippi basin. Fig. 1 illus-

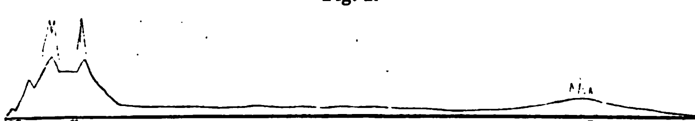
Fig. 1.



trates this form of the continent. In the section, *b* represents the Rocky Mountain chain on the west, with its double line of ridges at summit; *a*, the Washington chain (including the Sierra Nevada and Cascade range) near the Pacific coast; *c*, the Mississippi basin; *d*, the Appalachian chain on the east.

South America, in a similar manner, has the Andes on the west, the Brazilian Mountains on the east, and other heights along the north, with the low region of the Amazon and La Plata making up the larger part of the great interior. Fig. 2 is a transverse section from west to east

Fig. 2.



(W, E), showing the Andes at *a* and the Brazilian Mountains at *b*. In these sections the height as compared with the breadth is necessarily much exaggerated.

In the Orient, there are mountains on the Pacific side, others on the Atlantic; and, again, the Himalayas on the south face the Indian Ocean, and the Altai face the Arctic or Northern Seas. Between the Himalayas (or rather the Kuen-Luen Mountains, which are just north) and the Altai lies the plateau of Gobi, which is low compared with the enclosing mountains; and farther west there are the low lands of the Caspian and Aral, the Caspian lying even below the level of the ocean. The Urals divide the 6000 miles of breadth into two parts, and so give Europe some title to its designation as a separate continent. West of their meridian there are again extensive low lands over middle and southern European Russia.

In Africa, there are mountains on the eastern border, and on the western border south of the coast of Guinea; there are also the Atlas Mountains along the Mediterranean, and the Kong Mountains along the Guinea coast; and the interior is relatively low, although mostly 1000 to 2000 feet in elevation.

In Australia, also, there are high lands on the eastern and western borders, and the interior is low.

All the continents are, therefore, constructed on the *basin-model.*

2. *Relation between the heights of the borders and the extent of the adjoining ocean.*—There is a second great truth with regard to the continental reliefs; namely, that *the highest border faces the largest ocean.*

By largest ocean is meant not merely greatest in surface, but *greatest in capacity*, the depth being important in the consideration. The Pacific, both in depth and surface, greatly exceeds the Atlantic; so the South Pacific exceeds the North Pacific and the South Atlantic exceeds the North Atlantic. The Indian Ocean is also one of the large oceans; for it extends eighty degrees of latitude south of Asia before reaching any body of Antarctic land; and this is equivalent to 5500 miles, nearly the mean breadth of the Pacific: moreover, as it is much more free from islands than the Pacific, it is probably *the deeper* of the two, and, consequently, yields in capacity to no other ocean on the globe.

Each of the continents sustains the truth announced.

North America has its great mountains, the Rocky chain, on the side of the great ocean, the Pacific; and its small mountains, the Appalachian, on the side of the small ocean. So, South America has its highest border on the west; and the Andes as much exceed in elevation and abruptness the Rocky chain as the South Pacific exceeds in capacity the North Pacific. The Orient has high ranges of mountains on the east, or the Pacific side, and lower, as those of Norway and other parts of Europe, on the west; and the Himalayas, the highest of the globe, face the great Indian Ocean (besides being most elevated eastward towards the great Pacific), while the smaller Altai face the small Northern Ocean. In Africa the eastern mountains, or those on the Indian Ocean side, are higher than those on the Atlantic. In Australia the highest border is on the Pacific side; for the South Pacific, taking into view its range in front of east Australia, is greater than the Indian Ocean fronting west Australia.

Hence the basin-shape, before illustrated, is that of a basin with one border much higher than the other, and the highest border the one that adjoins the largest ocean.

These features have a vast influence in adapting the continents for man.

America stands with its highest border in the far *west*, and with all its great plains and great rivers inclined towards the Atlantic; for through the Gulf of Mexico the whole interior, as well as the eastern border, has its natural outlet *eastward*. Had the high mountains of the continent been placed on its *eastern* side, they would have condensed the moisture of the winds before they had traversed the land, and sent it back, in hurrying and almost useless torrents, to the ocean; but, being on the *western*, all the slopes from the Atlantic to the tops of the Rocky Mountains lie open to the moist winds, and fields and rivers show the good they thus receive.

Again, the Orient, instead of rising into Himalayas on the Atlantic border, has its great heights in the remote *east*, and its vast plains and the larger part of its great rivers, even those of central Asia, have their natural outlet *westward*, or towards the same Atlantic Ocean. Thus, as Professor Guyot has said, the vast regions of the world which are best fitted by climate and productions for man are combined into one great arena for the progress of civilization. Both the Orient and the Occident pour their streams and bear a large part of their commerce into a common ocean; and this ocean, the Atlantic, is but a narrow *ferriage* between them, and vastly better for the union of nations than connection by as much dry land: 3000 miles of dry land would be, even in the present age, a serious obstacle to intercourse; while 3000 miles of ocean draw the east and west only into closer political, commercial, and social relations.

PART II.

LITHOLOGICAL GEOLOGY.

The term *rock*, in geology, is applied to all natural formations of rock-material, whether solid or otherwise. Not only are sandstones and slates called rocks, but also the loose earth, sand, and gravel of the surface, provided they have been laid out in beds by natural causes. All sandstones were once beds of loose sand; and there is every shade of gradation from the hardest sandstone to the softest sand-bed: so that it is impossible to draw a line between the consolidated and unconsolidated. Geology does not attempt to draw the line, but classes all together as *rocks*, regarding *consolidation* as an accident that might or might not happen in the case of the earth's beds or deposits.

Rocks may be studied simply as rocks,—that is, with reference to their composition,—and collections may be made containing specimens of their various kinds. Again, they may be studied as rock-masses spread out over the earth and forming the earth's crust; and, with this in view, the condition, structure, and arrangement of the great rock-masses (called sometimes *terrains*) would come up for consideration. The two subjects under Lithological Geology are, therefore: (1.) *The constitution of rocks;* (2.) *The condition, structure, and arrangement of rock-masses.*

1. CONSTITUTION OF ROCKS.

1. General Observations on their Constituents.

Rocks consist essentially of mineral material. The following are the most common kinds.

1. **Quartz, or Silica.**—*Quartz*, or, as it is called in chemistry, *silica*, far exceeds all other species in abundance. It is one of the hardest of minerals; it does not melt before the blowpipe, and does not dissolve in water. Its hardness and durability especially fit it for this place of first importance in the material of the earth's foundations.

It often occurs in crystals of the forms represented in figs. 3, 4, though generally occurring in grains, pebbles, or masses. It is distinguished ordinarily by its glassy aspect, whitish or grayish color, and an absence of all tendency to break with a smooth surface of fracture (a quality of crystals called *cleavage*). Although usually nearly colorless or white, it is very often reddish, yellowish, brownish (especially smoky brown), and even black; and the lustre is sometimes very dull, as in *chalcedony*, *flint*, and *jasper*. The sands and pebbles of the sea-shores and gravel-beds are mostly quartz,—because quartz resists the wearing action of waters better than any other common mineral. For the same reason, most sandstones and conglomerates consist mainly of quartz.

Fig. 3.

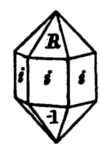
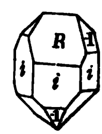


Fig. 4.



The hardness (on account of which it scratches glass easily), infusibility, insolubility, non-action of acids, and absence of cleavage, are the characters that serve to distinguish quartz from the other ingredients of rocks.

Although quartz is one of the original minerals of the earth's crust, the quartz of rocks is not all directly of mineral origin. Part of it—perhaps a large part—has passed through living beings, either plants or animals; for some of the lowest species of these kingdoms of life have the power of making siliceous shells or forming siliceous particles or spicules in their texture; and beds have been made of these microscopic siliceous shells. The animal species that secrete spicules of silica are the *Sponges;* and those making siliceous shells are the microscopic forms called *Polycystines.* The plants making siliceous shells are the microscopic kinds called *Diatoms.* (See page 61.)

2. **Silicates.**—Silica also occurs in many of the other rock-making minerals, constituting what are called *silicates.* It exists, thus, in combination with the bases *alumina, magnesia, lime, potash, soda,* the *oxyds of iron,* and a few others.

Pure *alumina,* the most important of the above-mentioned bases in the silicates, is hard, infusible, and insoluble, and therefore adapted to be next in abundance to silica. When crystallized, it is the hardest of all known substances, excepting the diamond, it being the gem *sapphire.* A massive or rock-like variety, reduced to powder, is *emery.*

Magnesia, well known under the form of *calcined magnesia,* is as hard as quartz when crystallized, and equally infusible and insoluble.

Lime is common quick-lime. *Potash* and *soda* are the alkalies ordinarily so called. These three ingredients are found in those silicates that contain also either alumina or magnesia, or both. The same is true, for the most part, of the *oxyds of iron.* The compounds they form have a degree of fusibility that does not belong to the simple alumina-silicates, and which fits them for being the constituents of igneous or volcanic rocks. The following are the most common of these silicates:—

(1.) *Feldspar.*—Feldspar consists of *silica* and *alumina* along with *lime, potash,* or *soda.* Common feldspar, or *orthoclase,* contains mainly *potash,* along with the silica and alumina; *albite* contains, in place of the potash, *soda;* and *labradorite*, another kind of feldspar, contains mainly *lime*. The specific gravity is 2.4–2.7.

Either of these kinds of feldspar is distinguished from quartz by having a distinct cleavage-structure, the grains or masses breaking easily in two directions with a flat and shining surface. They are nearly as hard as quartz, often white, but sometimes flesh-red. The albite is usually white; and the labradorite often brownish, with generally a beautiful play of colors.

(2.) *Mica.*—Mica consists of *silica* and *alumina*, along with *potash*, *lime*, *magnesia*, or *oxyd of iron*. It cleaves easily into tough leaves, thinner than the thinnest paper and somewhat elastic. On account of its transparency, when colorless, it is often used in the doors of stoves. Its most common colors are whitish, brownish, and black.

The minerals quartz, feldspar, and mica are the constituents of granite; and they may be distinguished in it as follows: the *quartz* by its more glassy lustre and want of cleavage; the *feldspar* by its being more opaque than quartz, and its having cleavage; the *mica* by its very easy cleavage into thin, elastic leaves.

(3.) *Hornblende and pyroxene.*—Hornblende and pyroxene consist, alike, of *silica* along with *magnesia*, *lime*, and *protoxyd of iron*. They are both of dark-green, greenish-black, and black colors in most of the rocks formed of them, though sometimes gray and white. Both are cleavable. Hornblende often occurs in slender needle-shaped crystals. There are fibrous varieties of each, called *asbestus*. They are nearly as hard as feldspar, but much heavier than it (specific gravity = 3–3.5), and in general much more fusible.

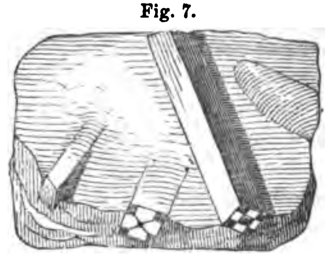
(4.) *Garnet—Tourmaline—Andalusite.*—These are other silicates, of very common occurrence in rocks. They are usually found in crystals distributed through a rock. *Garnet* is commonly in dark red, brownish, or black crystals of 12 or 24 sides (dodecahedrons or trapezohedrons). The first of these forms is represented in fig. 5, showing garnets distributed through a mica schist. *Tourmaline* is generally

Fig 5.

Fig. 6.

in oblong 3, 6, 9, or 12 sided crystals, shining and black; also at times blue-black, brown, green, and red. The crystals are common in gneiss and mica schist, and are at times imbedded in quartz (fig. 6). Andalusite is found in imbedded crystals in argillaceous schist: the form is nearly a square prism. The interior of the crystals is very frequently black or grayish-black at the centre and angles (fig. 7), while the rest is nearly white; and this variety is called *macle*, or *chiastolite*.

Fig. 7.



(5) *Talc and serpentine.*—Talc and serpentine are compounds of silica with magnesia and water. They both have a greasy feel,—especially the talc. Talc is a very soft mineral. It is often in foliated plates or masses like mica; but the folia, or leaves, though separating rather easily and flexible, are not elastic. The usual color is pale green.

A massive granular talc, of whitish, grayish, or greenish color, is called *soapstone*, or *steatite*. Serpentine is harder than talc. It occurs as a dark-green massive rock, of a very fine-grained texture: it is rarely foliated, and when so, the leaves are not easily separated and are brittle. It may be carved with a knife, and it differs in this, and also in its being lighter, from compact hornblendic rocks.

3. **Carbon, Carbonic Acid, Carbonates.**—(1.) *Carbon.*—Carbon is familiarly known under three names and conditions: (1.) *Diamond;* (2.) *Charcoal;* (3.) *Graphite.* The last is the material of *lead-pencils*, and is called also *black lead*, though containing no lead. The first is the hardest of all known substances; the last, one of the softest.

In Geology, carbon is most important in the state of *mineral coal*, which is carbon mixed with other ingredients, especially some of a bituminous kind. The variety containing bitumen or bituminous substances burns on this account with a bright flame, and is called *bituminous coal.* The harder kind, with little or no bitumen, burning with a very feeble-bluish or yellowish flame, is *anthracite.*

(2.) *Carbonic acid* is a gas consisting of carbon and oxygen. It composes about 4 parts by volume of 10,000 parts of the atmosphere, is formed in all combustion of wood or coal, and is given out in the respiration of animals. Its principal geological importance depends upon its being one of the constituents of limestone.

(3.) *Carbonate of lime*, or *calcite*, the essential ingredient of limestone and marble, consists of *carbonic acid* and *lime.* It crystallizes in a great variety of forms, a few of which are represented in figs. 8, 9. It cleaves easily in three directions with bright surfaces; as may be seen on examining even the grains of a fine white marble. It is rather soft, so as to be easily scratched with a knife; dissolves in diluted acids (chlorohydric or sulphuric) with effervescence, that is, with an escape of the gas carbonic acid; and when heated (as in a lime-kiln, or before the blowpipe) it burns to *quick-lime* without melting. By its effervescence with acids it differs from all the minerals before mentioned.

Fig. 8.

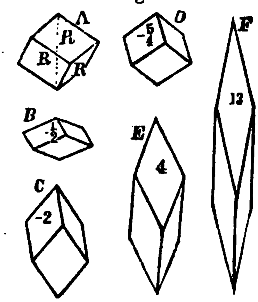
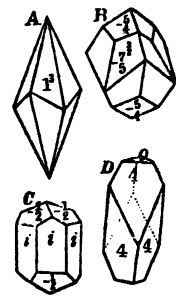


Fig. 9.



(4.) *Dolomite* is a carbonate of lime and magnesia; that is, it differs from calcite in containing magnesia in place of part of the lime. It makes up the mass of a variety of limestone called *magnesian* limestone, which closely resembles common limestone, but may be distinguished by its effervescing scarcely at all with acid unless heat be applied. The trial may be made by dropping a particle, as large as half a grain of wheat, into a test-glass one-quarter filled with a mixture, half and half, of muriatic acid and water.

The larger part of the carbonate of lime of rocks has been derived directly from shells, corals, and other animal remains. Animals take the material of their shells and other stony structures from the waters of the globe, or from the food they eat, through their power of secretion,—that is, the same power by which man forms his bones. After death, the shells, corals, or bones, which are of no further use to the species, are turned over to the mineral kingdom to be made into rocks. The immense extent and thickness of the earth's limestone rocks, nearly all of which are probably of organic origin, give some idea of the amount of life that has lived and died through past time.

Carbonate of lime and *silica* are the two stony ingredients which have been contributed largely by living species to the earth's rock-formations. *Mineral coal* is another material abundantly contributed by the kingdoms of life, the great beds of the coal period being all made from the leaves and other parts of plants.

Sand—Clay.—Sand and clay are not minerals: they are mixtures of minute particles of different minerals, produced by the wearing down of different rocks. A large part of common clay is pulverized feldspar mixed with some quartz. Other kinds, having a greasy feel in the fingers, consist of a material derived from the decomposition of feldspar and allied minerals, and are composed of alumina, silica, and water, mixed more or less with quartz and other impurities.

2. Kinds of Rocks.

1. **Fragmental and Crystalline rocks.**—The minerals of which a rock consists may be either (1) in *broken* or *worn* grains or pebbles, like those of sand or clay or a bed of pebbles; or (2) they may be in *crystalline* grains, in which case they were formed where they now are at the time of the crystallization of the rock. Such crystalline grains are angular, and almost always show surfaces of cleavage.

The rocks of the first kind, consisting of a mingling of fragments of other rocks, are called *fragmental* rocks; and those of the latter kind, *crystalline* rocks. The sands of a sea-shore or the mud of a sea-bottom may make a *fragmental* rock no less than coarser deposits.

Fragmental rocks are often called, also, *sedimentary* rocks, because formed in general from *sediment*, or the earth deposited by waters, either those of the ocean, lakes, or rivers.

Intermediate between rocks that are obviously either *fragmental* or *crystalline*, there are others, of a flinty compactness, which show no distinct grains, and are, therefore, not easily referred to either division. In the case of such rocks, the geologist, in order to determine the division to which they belong, has to examine the rocks associated with them. If these associated rocks are *fragmental*, then the compact beds are probably so also; but if these are *crystalline*, then they are probably related to the crystalline. Experience among rocks is required to decide correctly in all such cases.

2. **Metamorphic and Igneous rocks.**—The crystalline rocks are either *metamorphic*, or *igneous*.

1. *Metamorphic rocks* are those which have been altered or *metamorphosed* by means of heat. The alteration, when most complete, consists in a complete crystallization of the rock; and when less so, in a consolidation or baking of it, with sometimes no distinct crystallization.

Earthy sandstones and clay-rocks have been thus metamorphosed into *granite, gneiss,* and *mica schist*, and ordinary limestone into *statuary marble.*

2. *Igneous rocks* are those which have been ejected in a melted state, as from volcanic vents, or from fissures opened to some seat of fires below or within the earth's crust.

3. **Calcareous rocks.**—Calcareous rocks are the *limestones.* To a great extent they have been formed from pulverized animal relics, such as *shells* and *corals;* and in this case they are properly *fragmental* or *sedimentary* beds, although so finely compact that this might not be suspected from their texture.

Some limestones have been made from the accumulation and consolidation of very minute shells, called *Rhizopods.* These shells being no larger than the finest grains of sand, no powdering was necessary. The limestone rocks formed of them are *not fragmental* in origin.

Other calcareous rocks have been deposited from waters holding the material in solution, and are, therefore, of *chemical* origin. Of this kind is the *travertine* of Tivoli near Rome in Italy, and similar beds in many regions of mineral springs, besides the petrified moss and trees of some marshy regions.

4. **Massive, schistose, laminated, slaty, shaly rocks.**—Rocks are termed *massive*, when there is no tendency to break into

slabs or plates; *schistose*, when crystalline and having a tendency to break into slabs or plates, arising from the arrangement more or less perfectly in layers of the mineral ingredients (especially mica or hornblende); *laminated*, when breaking into slabs or flagging-stones, and not in consequence of a crystalline structure; *slaty*, when dividing easily into thin, even, hard slates, like roofing-slate; *shaly*, when dividing easily into thin plates like a slate-rock, but the plates irregular and fragile.

The term *schist* is applied to a schistose rock; *flag*, to a laminated rock; *slate*, to a slaty rock; *shale*, to a shaly rock.

The *kinds of rocks* may be described under the four heads:—(1) *Fragmental* rocks, not calcareous; (2) *Metamorphic rocks*, not calcareous; (3) *Calcareous rocks;* (4) *Igneous rocks.*

1. Fragmental Rocks.

1. *Sandstone.*—Composed of sand, coarse or fine. When of pure quartz sand, the rock is a *siliceous sandstone;* and if very hard and a little pebbly, a *grit.* When earthy or clayey, it is an *argillaceous sandstone*, the term argillaceous meaning *clayey.* Argillaceous sandstones are usually laminated, and, when very hard, may make good flagging-stone.

2. *Conglomerate.*—Containing rounded or angular pebbles. If *rounded* pebbles, the rock is often called a *pudding-stone;* and if *angular* fragments, a *breccia;* if the pebbles are of quartz, a *siliceous conglomerate;* if of limestone, a *calcareous conglomerate.*

3. *Shale.*—Composed of clay or clayey earth, and having a shaly structure. The colors are of all dull shades from gray to black. When the shaly structure is very imperfect and the rock is quite fragile, it is a *marlite.* [It is often called, though not correctly, a *marl:* a *true marl* is a clay containing carbonate of lime derived generally from powdered or broken shells.]

4. *Tufa.*—A kind of volcanic sandstone, composed of volcanic sand or pulverized volcanic rocks: color, usually brownish, brownish-yellow, grayish, and reddish.

2. Metamorphic Rocks.

1. *Granite.*—A crystalline rock, consisting of quartz, feldspar, and mica. Color, usually light or dark gray or flesh-red, the latter shade derived from a flesh-colored feldspar.

2. *Gneiss.*—Closely like granite in composition, but somewhat schistose, and, consequently, having a banded appearance on a surface of fracture transverse to the structure, arising from the arrangement of the mica. If the color of the gneiss is dark gray, it is banded usually with black lines. Along the micaceous planes it breaks rather easily into slabs, which are sometimes used for flagging.

3. *Mica Schist.*—Related to gneiss, but consisting mainly of mica, with more or less of feldspar and quartz, and, in consequence of the mica, breaking into thin slabs. The slabs have a glistening surface. In regions of mica schist the dust of the roads is often full of shining particles of mica.

4. *Syenite—Hornblendic Gneiss—Hornblendic Schist.*—*Syenite* resembles granite, but contains *hornblende* in place of mica: the hornblende may be distinguished from mica by its less perfect cleavage, and by the brittleness of the laminæ afforded with some difficulty by the cleavage. A rock like gneiss, but containing hornblende in place of mica, is called *hornblendic gneiss.* A black or greenish-black schistose rock consisting almost wholly of hornblende is called *hornblendic schist.*

5. *Talcose Schist.*—A slaty rock containing some talc, and having, therefore, a greasy feel. Color usually grayish-green, greenish, or brownish.

6. *Chlorite Schist.*—A slaty rock containing an olive-green mineral called chlorite, which is related to talc in

being magnesian, but contains oxyd of iron, and is hardly greasy in feel. Color, dark green, and often olive green.

7. *Slate, Argillite, Argillaceous Schist.*—These are different names of roofing-slate and the allied slaty rocks. The texture is hardly at all crystalline, but the slates in the most perfect kinds are hard, smooth in surface, and not absorbent of water. Color blue-black, purplish, greenish, and of other shades.

There is a gradual passage of the above rocks from granite into gneiss; from gneiss into mica schist; and from mica schist and talcose schist into argillaceous schist.

8. *Quartz Rock—Quartzite.*—There is also a gradual passage, through the more or less complete absence of the feldspar, into a *micaceous quartz rock* having a schistose structure; and, by a more or less complete absence of the mica into a pure massive *quartz rock*, called also *quartzite.* Quartzite is only a very firmly consolidated sandstone made of quartz sand. The consolidation has been produced by the aid of heat, just as crystallization into gneiss has been produced. For the former the sandstones were purely siliceous, or nearly so, and for the latter, earthy sandstones.

9. *Itacolumite.*—A peculiar laminated quartz rock occurs in many gold-regions, which bends without breaking, when in large thin plates. It contains scales of mica or talc, and owes to this its laminated structure, toughness, and flexibility.

3. Calcareous Rocks.

a. Uncrystalline.

1. *Common Limestone.*—A compact rock, of grayish and other dull shades of color to black, breaking with little or no lustre, and with either a slightly rough or a smooth surface of fracture. Consists essentially of carbonate of lime, though often very impure from the presence of clay or earth. When containing fossils, it is called *fossiliferous* limestone.

When consisting of carbonate of lime and magnesia, it is a *magnesian* or *dolomitic* limestone, or *dolomite*, a kind not distinguishable by the eye from ordinary limestone. For the distinctive characters, see page 17.

Many varieties of common limestone are polished and used as *marbles*. The black marbles, and some of the yellow and gray, are of this kind. Frequently they contain fossils.

2. *Oolite.*—A limestone consisting of concretions as small as the roe of fish,—whence the name, from the Greek *ōon*, *egg*. Oolites or oolitic limestones occur in all the geological formations, and are forming in modern seas about some coral reefs.

3. *Travertine.*—See page 21.—*Stalactites* are limestone concretions, of the form of icicles, hanging from the roofs of caverns; and *Stalagmite* is the same material covering their floors. The waters trickling through limestone rocks hold some carbonate of lime in solution (in the state of bicarbonate); and its deposition, as the dropping water evaporates, produces these concretions and incrustations.

b. Crystalline.

Granular Limestone—Statuary Marble.—Limestone having a crystalline granular texture, and, consequently, glistening on a surface of fracture. The pure white kind, looking when broken much like loaf-sugar, is, when of firm texture, the marble used for statuary; and both this and coarser varieties are employed for marble buildings. Most of the clouded marbles are here included.

4. Igneous Rocks.

1. *Granite-like Rocks.*—Granite is usually regarded as a true igneous rock. But igneous rocks contain ordinarily little or no silica in the condition of quartz. There are several kinds of whitish and grayish crystalline igneous rocks consisting of feldspar and hornblende, or feldspar and

pyroxene, or feldspar alone, each containing little or no quartz. Mica is sometimes present in rocks of this kind.

2. *Diorite.*—Consists of a *feldspar* (albite) and *hornblende;* and, though it may be light-colored from the abundance of the feldspar, it is usually dark green and greenish-black, from the preponderance of the hornblende.

3. *Dolerite.*—Consists of a *feldspar* (labradorite) and *pyroxene*, and has greenish-black, brownish-black, and black colors. It is also often called *trap.* It may be either crystalline granular, or of a flinty compactness. It frequently contains also grains of magnetic iron ore.

4. *Basalt.*—Like *dolerite*, but containing grains of a green siliceous mineral, of a bottle-glass green color, called *chrysolite* or *olivine.*

5. *Trap.*—Basalt, dolerite, and the diorites, especially the dark-colored kinds, are often called *trap*, or *trappean* rocks.

6. *Porphyry.*—Consists of feldspar (orthoclase) in a compact condition, and contains crystals of feldspar of a paler color and often whitish; so that a polished surface is covered with angular spots. Common colors, green and red.

Granite, *dolerite*, *basalt*, and other rocks are said to be *porphyritic* when the feldspar is in distinct crystals.

A large part of the so-called porphyry is of *metamorphic* origin, and not a true igneous rock. It sometimes consists in part of hornblende or quartz.

7. *Trachyte.*—Consists of feldspar, and has a rough surface of fracture. Usually contains small air-cells, and also disseminated crystals of a glassy feldspar.

8. *Lava.*—Any rock that has flowed in streams from a volcano, especially if it contains cavities, or, in other words, is more or less scoriaceous. It is usually a *dolerite*, *basalt*, or *trachyte* in composition.

9. *Scoria* is a light lava, full of cavities, like a sponge; and *pumice*, a white or grayish feldspathic scoria, having the air-cells long and slender, so that it looks as if it were fibrous.

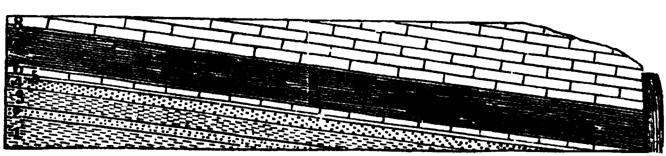
2. CONDITION, STRUCTURE, AND ARRANGEMENT OF ROCK-MASSES.

The rocks which have been described are the common material of which the great rock-masses of the globe consist. These rock-masses occur under three conditions:—(1) the *stratified;* (2) the *unstratified;* (3) the *vein-form.*

1. **The Stratified condition.**—Stratified rocks are those which lie in beds or strata. The word *stratum* (the singular of strata) is from the Latin, and signifies that which *is spread out.* The earth's rocky strata are spread out in beds of vast extent, many of them covering thousands of square miles. The stratified rocks exposed to view over the earth's surface far exceed in area the unstratified.

They are the rocks of nearly the whole of the United States and of nearly all of North America, and not less of the other continents. Throughout central and western New York and the States south and west, the rocks, wherever exposed, are seen to be made up of a series of beds. And if the beds are less distinct over a large part of New England, it is, in general, only because they have been obscured by the upturning and crystallization which the rocks have undergone since they were formed.

Fig. 10.



The preceding figure represents a section of the rocks along the river below Niagara Falls. It gives some idea of the alternations which occur in the strata. In a total height of 250 feet (165 feet at the Falls, at F, on the right) there are on the left 6 different strata in view and parts of 2 others, the upper and lower, making 8 in all. 1 is gray argillaceous sandstone; 2, gray and red argillaceous sandstone and shale; 3, flagstone, or hard laminated sandstone; 4, reddish shale or marlite and shaly sandstone; 5, shale; 6, limestone; 7, shale; 8, limestone. Only two of these strata, 7 and 8, are in sight at the falls (at F). The alternations are thus numerous and various in all regions of stratified rocks.

It must not be inferred that the earth is covered by a regular series of coats, the same in all countries; for this is far from the truth. Many strata occur in New York that are not found in Ohio and the States west; and each stratum varies greatly in different regions, sometimes being limestone in one and sandstone in another.

A *stratum* is a bed of rock including all of any one kind that lie together, as either Nos. 1, 2, 3, 4, 5, 6, 7, or 8 in the preceding figure.

A *formation* includes the several strata that were formed in one age or period. A subdivision of a formation, including two or more related strata, is often called a *group*.

A *layer* is one of the subdivisions of a stratum. A stratum may consist of an indefinite number of *layers*.

2. **Unstratified condition.**—Unstratified rocks are those which do not lie in beds or strata. Mountain-masses of granite are often without any appearance of stratification. The rock of the Palisades, on the Hudson, stands up with a bold columnar front, and has no division into layers. There are similar rocks about Lake Superior. Most lavas of volcanoes have flowed out in successive streams; and, consequently, volcanic mountains are generally stratified. But in some volcanic regions the rocks rise into lofty summits without stratification. Although true granite bears no marks of proper stratification, it very often passes insensibly into gneiss, which is a stratified rock; and there is evi-

dence in this fact that granite is, generally, a stratified rock which has lost the appearance of stratification in consequence of the crystallization it has undergone.

3. **Vein-form condition.**—When rocks have been fractured, and the fissures thus made have been filled with rock-material of any kind, or with metallic ores, the fillings are called *veins*. Veins are therefore large or small,—deep or shallow,—single or like a complete network,—according to the character of the fractures in which they were formed. They

Fig. 11.

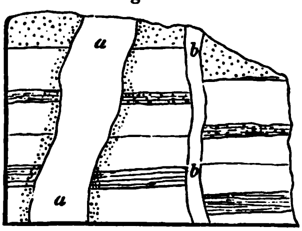
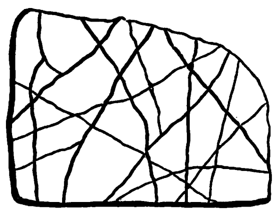


Fig. 12.



may be as thin as paper, or they may be many yards, or even rods, in width. Figures 11 to 14 represent some of them. In fig. 11 there are two veins, *a* and *b*; in fig. 12,

Fig. 13.

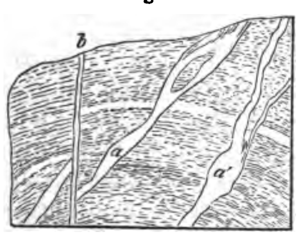
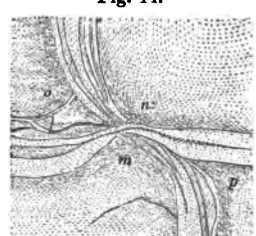


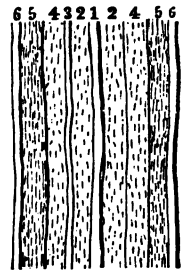
Fig. 14.



a network of thin veins; in fig. 13, two of irregular form,—a kind not uncommon; in fig. 14, two large veins, of still more irregular character, crossing one another.

Many veins have a banded structure, like fig. 15. In this vein, the layers 1, 3, 6, consisted of quartz; 2, 4, of gneissoid granite; 5, of gneiss. Most metallic veins are of this kind: the ores lie in one or more bands alternating with other stony bands consisting of different minerals or rock-material, as *calcite*, *quartz*, *fluor-spar*, etc.

Fig. 15.



Those veins that have been filled with melted rocks are usually called *dikes:* they are not banded, and have regular walls; and the rocks are igneous rocks. They are often transversely columnar in structure. Fig. 16 represents a dike, and shows this transverse columnar structure.

4. **Relation of stratified and true unstratified rocks and veins in the earth's crust.**—The relations of the stratified and unstratified rocks in the earth's crust will be understood after considering the origin of the crust.

Fig. 16.

The crust is believed to be the cooled exterior of a melted globe. After the first crusting over of the surface of the sphere, the ocean commenced to make *stratified* rocks over the exterior, while the continued cooling, going on very slowly, made *unstratified* rocks below. The ocean thus worked over and covered up with strata nearly all, *if not all*, the original unstratified crystalline rocks. Hence, true unstratified rocks—that is, those which were unstratified in their first formation—are of very small extent over the globe. Even ordinary granite, as mentioned on page 29, is not generally of this kind. Veins are a result of *fractures* of the crust; and they too are of very limited distribution.

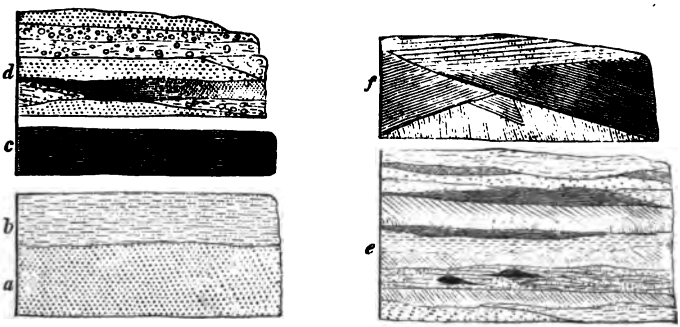
Geology, consequently, has for its study, almost solely stratified rocks. Nearly all the facts in geological history are derived from rocks of this kind. It is, therefore, important that the various details with regard to their structure and arrangement should be well understood by the student.

STRATIFIED CONDITION.

1. Structure.

1. *Massive, laminated, and shaly structures.*—The massive, laminated, and shaly structures of layers have been explained on p. 21. The *massive* is represented in fig. 17 *a;*

Fig. 17.



the *laminated*, in fig. 17 *b;* and the *shaly*, in fig. 17 *c*. Sandstone is more or less laminated, according to the proportion of *clay* or *earthy material* it contains. The same is true of limestone.

2. *Beach-structure.*—The beach-structure is illustrated in fig. 17 *d*. The layer, instead of being composed of evenly-laid material, consists of many irregular small layers,—beds of sand and others of pebbles, of small extent, being variously mingled. This kind of layer is formed along sea-beaches, being well shown wherever a sea-beach is cut through, so that the interior is open to view.

3. *Ebb-and-flow structure.*—The ebb-and-flow structure is

illustrated in fig. 17 *e*. A layer presenting it consists of irregular subordinate layers, like those of beach origin; but these subordinate layers are of wider extent, and part of them are obliquely laminated (see figure,) while other alternate layers are laminated horizontally. Such a structure is formed where currents intermit at intervals or are reversed, as in the ebb and flow of the tides where they are connected with heavy tidal waves.

4. *Wind-drift structure.*—A layer characterized by the wind-drift structure consists of layers dipping in various directions, sometimes curving and sometimes straight. (Fig. 17 *f*.) The hills of sand formed by the winds on a sea-coast usually have this structure. The sands drifted over the rising heaps form layers conforming to the outer surface, and so may slope at all angles. In storms they may be blown away in part, and afterwards be completed again; but then the layers, conforming to a new outer surface, would have a different direction. In this way, by successive

Fig. 18.

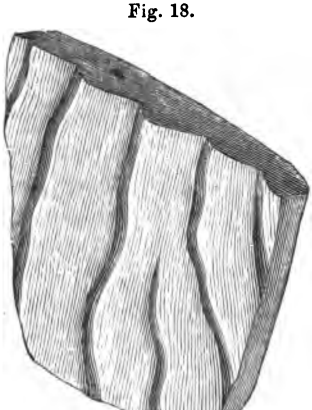
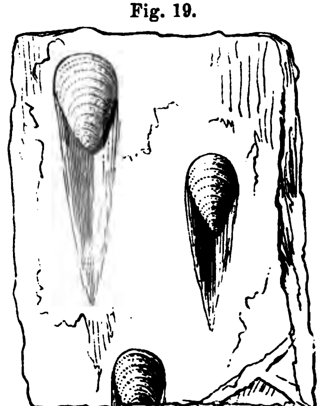


Fig. 19.



destructions and re-completions, a bed of sand may be made which shall consist of parts sloping in one direction and other parts in directions very different, with numerous abrupt transitions, as illustrated in the drawing.

5. *Ripple-marks.*—A gentle flow of water or its vibration, over mud or sand, ripples the surface. Sandstone and clayey rocks are often covered with such ripple-marks. (Fig. 18.)

6. *Rill-marks.*—When the waters of a spreading or returning wave on a beach pass by shells or stones lodged in the sand, the rills furrow out little channels. Fig. 19 shows such rill-marks alongside of shells in a Silurian sandstone.

7. *Mud-cracks.*—When a mud-flat is exposed to the air or sun to dry, it becomes cracked to a few inches or so in depth. Fig. 20 represents mud-cracks in an argillaceous sandstone. The cracks were subsequently filled with stony material, which was harder even than the rock itself; so that the filling stands prominent above the general surface, and is actually a network of veins.

Fig. 20.

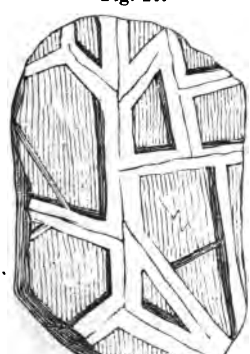
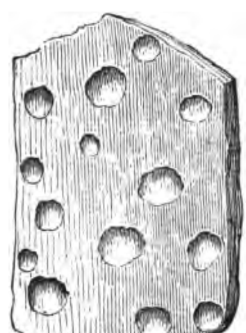


Fig. 21.



8. *Rain-prints.*—The impressions of rain-drops on sand or a half-dry mud have often been preserved in the rocks, appearing as in fig. 21.

9. *Concretionary structure.*—Layers often contain spheres

or disks of rock, which are called *concretions*. They result from a tendency in matter to concrete or solidify around centres. Some are no larger than grains of sand or the roe of fish, as in oolitic limestone (p. 25). Others are as large as peas or bullets, and others a foot or more in diameter. Fig. 22 is one of a spherical form. Fig. 23 represents a rock made up of rounded concretions. It shows also that they have sometimes (though not always) a concentric structure. In fig. 24 the concretions are flattened.

Fig. 22.

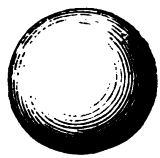


Fig. 23.

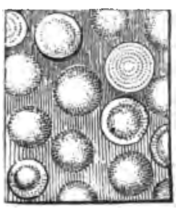


Fig. 24.

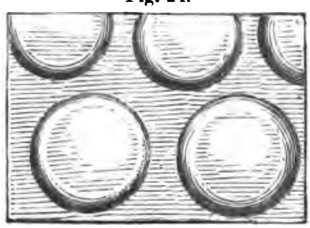
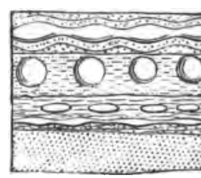


Fig. 25.



Concretions are usually *globular* in sandstones, *lenticular* in laminated sandstones, and *flattened disks* in argillaceous rocks or shales. All these kinds are shown in fig. 25. The balls are sometimes hollow, and the disks mere rings. Frequently the concretions have a shell or other organic object

Fig. 26.

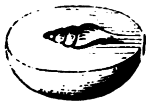


Fig. 27.

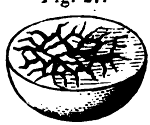
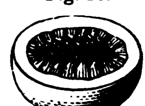


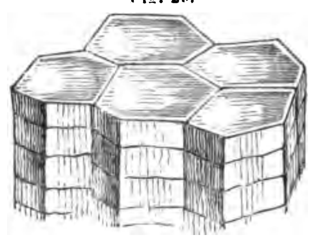
Fig. 28.



at centre (fig. 26). They are often cracked through the interior (fig. 27), the outside in such a case having solidified while the inside was still moist, and the latter afterwards cracking as it dried: in such a case the cracks may become filled with other minerals, so that the concretion, on being sawn in two and polished, may have great beauty. When hollow, they may be afterwards incrusted within by crystals (fig. 28) as of quartz, or by layers as of agate, and thus make what is called a geode; or they may become wholly filled. Sometimes they contain a loose ball within,—a concretion within a concretion.

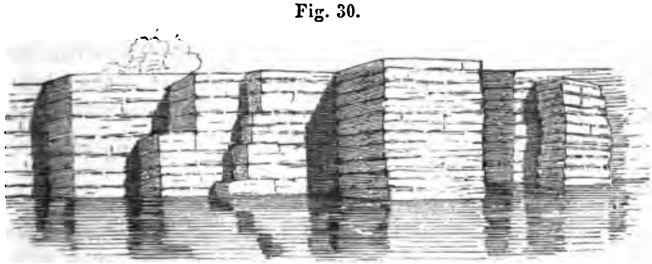
Basaltic columns (fig. 29), as they are often called, are columns of igneous rock made by the contraction of the mass when cooling from fusion. The size of the columns depends on a concretionary structure forming at the time within. The tops of the columns are often concave, or they become so as the rock decomposes.

Fig. 29.



10. *Jointed structure.* — The rocks of a region are often divided very regularly by numerous *straight planes of fracture*, all *parallel* to one another, and cutting through to *great depths*. Such planes of fracture may characterize the rocks for hundreds of miles. They are

Fig. 30.



called *joints;* and a rock thus divided is said to present a *jointed structure.* In many cases there are two systems of joints in the same region, crossing one another, so that they divide the rock into angular blocks, or give to a bluff a front like that of a fortification or a broken wall, as shown in fig. 30, —a view from the shores of Cayuga Lake. The directions of such joints are facts which the geologist notes down with care.

11. *Slaty cleavage.*—The term slaty has been explained on page 22. But one important fact regarding the structure is not there stated, which is, that the slates are always *transverse to the bedding*, that is, they cross the layers of stratification more or less obliquely, instead of conforming to the layers like the shaly structure. Slaty cleavage is in this respect like the jointed structure; but it differs in having the planes of fracture or divisional planes so close and numerous that the rock divides into slates instead of blocks.

Slaty cleavage is confined to fine-grained argillaceous

Fig. 31.

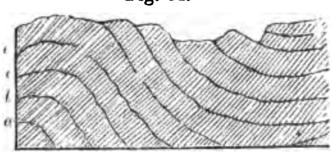
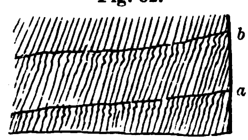


Fig. 32.



rocks. If a rock is a coarse argillaceous rock or an argillaceous sandstone, it may have a jointed structure, but will not have the true slaty cleavage. In fig. 31 the lines of bedding or stratification are shown at *a*, *b*, *c*, *d*, while the transverse lines correspond to the direction of the slates. The same is shown in fig. 32, with the addition of a slight irregularity in the slates along the junction of two layers.

2. Positions of Strata.

1. **Original position of strata.**—*Horizontal position.*—Ordinary stratified rocks were once beds of sand or earth, or of other kinds of rock-material, spread out for the most part by the currents and waves of the ocean, but partly by the waters of lakes or rivers.

When the larger portion of the beds over the North American continent were formed, the continent lay to a great extent beneath the ocean, as the bottom of a great, though shallow, continental sea. The principal mountain-chains—the Rocky Mountains and the Appalachians—had not yet been made, and the surface of the submerged land was nearly flat. The fact that the beds were really marine is proved by their containing, in most cases, sea-shells or corals, the relics of marine life; and the great extent of the continental seas is indicated by the beds covering areas of tens of thousands of square miles, some of them extending from the Atlantic border westward beyond the Mississippi. In such great seas, having the bottom nearly flat, the deposits made by means of the currents and waves would be nearly or quite *horizontal*. As they increased, they would near the surface; and here the action of the waves would level off the upper surface of the beds, whether accumulations of sand or earth, or of shells or corals. And if the bottom were very slowly sinking, the accumulations would still go on thickening, and the beds continue to have the same level or *horizontal* position.

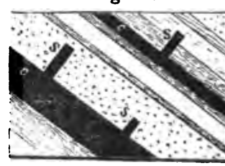
Many strata have been formed along the borders of the continents; and here, also, they take horizontal positions. The bottom of the border of the Atlantic, south of Long Island, is, for 80 miles from the coast-line, so nearly horizontal that, in a distance outward of 600 to 700 feet, it deepens on an average only 1 foot; and if the area were above the ocean, no eye would detect that it was not perfectly level. It is obvious that deposits over such a continental border, as well as those of beaches, would be very nearly *horizontal*.

The deltas about the mouths of great rivers, like that of the Mississippi, cover sometimes thousands of square miles. They are made of the sands and earth brought down by the river and spread out by the currents of the river and ocean.

They are, therefore, examples of the deposition of rock-material on a scale of great extent; and various strata have been formed as deltas are formed. The beds of delta-deposits are always *horizontal* or nearly so.

Other beds were originally vast marshes, like the marshes of the present day, only larger. Such was the condition of those beds in the coal-formation that contain coal. Now, marshes have a horizontal surface; and marsh deposits, as they accumulate, have a horizontal structure. Many coal-beds contain stumps of trees (fig. 33) rising out of the coal; and they always stand vertically on the bed, however much it may be displaced, showing that the bed was horizontal when formed, or when the trees were growing.

Fig. 33.



Exceptions to a horizontal position.—When a river empties into a lake or sea, the bottom of which, near its mouth, is very steeply inclined, the deposits of detritus made by the river will for a while conform to the slope of the bottom,

Fig. 34.

as in fig. 34. When rivers fall down precipices, they make a steep bank of earth at the foot, whose layers, if any are observable, will take the slope of the bank.

But these and similar cases of exceptions to a horizontal position are of small extent.

2. **Dislocations of strata.**—Most of the strata of the globe have lost their original horizontal position, and are more or less inclined; some are even vertical or stand on end.

They are occasionally bent or folded as a quire of paper might be folded, only the folds are miles, or scores of miles, in sweep.

They have often also been fractured, and the separated parts have been pushed, or else have fallen, out of their former connections, so that the portion of a stratum on one side of the fracture may be raised inches, feet, or even miles, above that on the other side.

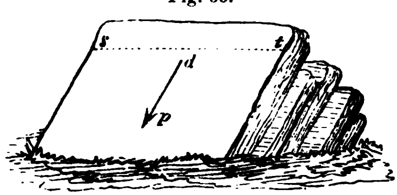
It is stated on p. 1, that a thickness of rock equal to 15 or 18 miles is open to the geological explorer. This could not be true, were all strata in their original horizontal position; for the most that would in that case be within reach would not exceed the height of the highest mountain. But the upturning which the earth's crust has undergone has brought the edges of strata to the surface, and there is hence no such limit: however deep stratified beds may extend, there is no reason why the whole should not be brought up so as to be exposed to view in some parts of the earth's surface.

The following are explanations of the terms used in describing the positions of strata:—

1. *Outcrop*.—The portions or ledges of strata projecting out of the ground, or in view at the surface (fig. 35).

2. *Dip*.—The angle of slope of inclined or *tilted* strata. In figures 35, 36, *d p* is the direction of the dip. Both the *angle* of slope and the *direction* are noted by the geologist:

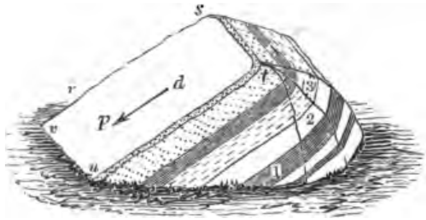
Fig. 35.



thus, it may be said of beds, the dip is 50° *to the south*, or 45° *to the northwest*, etc.

When only the edges of layers are exposed to view, it is not safe to take the slope of the edges as the slope of the layers; for in figure 36 the edges on the faces 1, 2, 3, 4, are

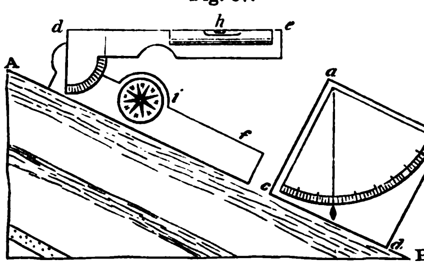
Fig. 36.



all edges of the same beds, and only those of the face 1 would give the right dip.

The *dip* is measured by means of instruments called *clinometers*. In fig. 37, *a b c d* represents a square block of

Fig. 37.

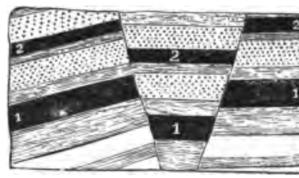


wood, having a graduated arc *b c* and a plummet hung below *a*. Placed on the sloping surface A B, the position of the plummet gives the angle of dip. This kind of clinometer is often made in the form of a watch and combined with a compass. In the same figure, *e d f* represents another clinometer. It has a level on the arm *d e;* and when the arm *d f* is placed on the sloping surface, the other arm is raised until, as shown by this level, it is horizontal; the *dip* is the angle between the two arms, as measured on the arc at the joint. To avoid errors from the unevenness of a rock, a board should be laid down first, and the measurement be made on its surface.

3. *Strike.*—The horizontal direction at right angles with the dip, as *s t* in fig. 35. The direction of the line of outcrop is often the true *strike.*

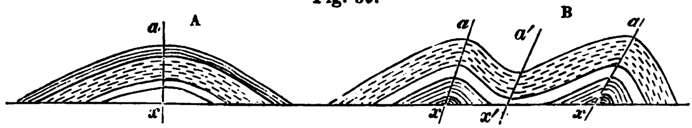
4. *Fault.*—When strata have been fractured and the parts are displaced, as in fig. 38, the displacement is called a *fault.* The coal-beds 1 and 2 in this figure are thus *faulted* in two places; and the amount of the fault in either is the number of feet or inches that one part is above or below the other.

Fig. 38.



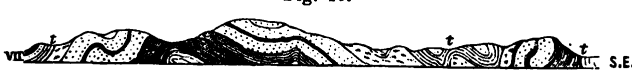
5. *Folds* or *flexures.*—The rising or sinking of strata in curving planes, as represented in the following sections, fig.

Fig. 39.



39, A, B; and in the natural section, fig. 40, from the Appalachian Mountains in Virginia.

Fig. 40.



In fig. 39, *a x* is the *axis* or axial plane of the fold.

6. *Anticlinal.*—Having the strata sloping *away from* a common line in opposite directions, as the layers either side of *a x* in fig. 39, A: the axis is here called an *anticlinal axis;* and a ridge made up of such strata is an *anticlinal ridge.* The word *anticlinal* is from the Greek *anti, in opposite directions,* and *klinō, I incline.*

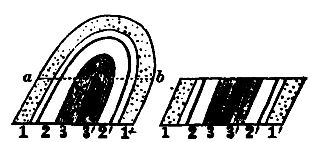
7. *Synclinal.*—Having the strata sloping *towards* a common line from opposite directions. In fig. 39, B, *ax*, *ax* are *anticlinal axes*, and *a′ x′*, between the others, a *synclinal axis;* or, viewing the former as *anticlinal ridges*, the latter is a *synclinal valley*. The word *synclinal* is from the Greek *sun*, *together*, and *klinō*, *I incline.*

8. *Monoclinal.*—Having the strata sloping in only one direction. A valley made by the fracture of strata and the slide of one side past the other, the *dip* of the two portions remaining unaltered or but little so, is called a *monoclinal valley*. The word *monoclinal* is from the Greek *monos*, *one*, and *klinō*.

9. *Geoclinal.*—Having the general mass of the earth's crust, but not the strata, sloping at surface towards a common axis of depression. Thus, a *geoclinal* valley is a depression of the surface produced by an uplift of the earth's crust on either side of the depression, without a simple synclinal dip in the strata bounding the depression,—as the Connecticut Valley, the Mississippi Valley.

10. *Denudation—Decapitated Folds.*—If the top of the fold in fig. 41 were cut off at *a b*, there would remain the part represented in fig. 42, in which there is no appearance of any fold, and only a uniform series of dips; and although 1′, 2′, 3′, might appear to be the *lower* strata of the series, they are actually parts of 1, 2, 3. A long series of such folds pressed together, and thus decapitated, would make a series of uniform dips over a wide extent of country.

Fig. 41. Fig. 42.



The wear of the ridges of a country by water has often produced the effect here described over regions of folded rocks.

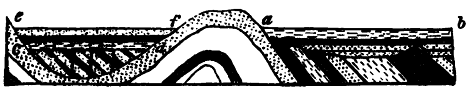
In other cases, a similar wear has removed the rocks over great areas, or filled up intermediate depressions by soil: so that the rocks are visible only at long intervals (as in fig.

Fig. 43.

43), and the *faults* which may exist are concealed from view. Many of the difficulties connected with the study of rocks arise from this cause.

11. *Unconformable strata.*—When strata have been tilted or folded, and, subsequently, horizontal beds have been laid down over them, the two sets are said to be *unconformable*,

Fig. 44.



because *they do not conform in dip.* It is a case of *unconformability* in the stratification. Thus, in fig. 44 the beds *a b* are unconformable to those below them; so also the tilted beds *c d* are unconformable to those beneath, and the beds *e f* to the beds *c d.*

It is plain that the folded rocks represented in figure 44 are the oldest, and that they were folded before *a b* or *c d* were deposited. Again, it is evident that the beds *c d* are older than the beds *e f*, and also that they were tilted and faulted before the beds *e f* were formed. Thus the geologist arrives at the relative periods of occurrences in geological time. If the precise age of the three sets of rocks here represented could in any case be ascertained (as they generally may be), the periods of uplift would be more precisely determined.

3. Order of Arrangement of Strata.

It has been explained that the strata are historical records of past conditions of the earth's surface. In order, therefore, that the records should make an intelligible history, all the parts should be arranged in their proper order, that is, *the order of time.* The determination of this *order* is one of the first things before the geologist in his examinations of a country.

Many difficulties are encountered.

1. The strata of the same period or time—called *equivalent strata*, because equivalent in age—differ, even on the same continent. Sandstones and shales were often forming along the Appalachians in Pennsylvania and Virginia, when limestones were in progress over the Mississippi Valley. The chalk formation in England contains thick strata of chalk; but in North America the same formation exists without any chalk.

2. When rocks have been forming in one region, there have been *none* in progress in many others. Hence the series of strata serving as records of geological events is nowhere perfect. In one country one part will be very complete; in another, another part; and all have their long blanks,—that is, large parts of the series entirely wanting. In New York and the States west to the Mississippi, there is only part of the lower half of the series. In New Jersey there is part of the lower half and part of the upper half, with wide breaks between. Over a large part of northern New York there is only the very earliest of rocks,—those made before the first fossiliferous beds were laid down.

The thickness of the fossiliferous series in the State of New York, south of its centre, is about 13,000 feet; and north of its centre they thin out to a few feet; in Pennsylvania, the maximum thickness is over 40,000 feet; in Indiana and other adjoining States west and south, 3500 to 6000 feet. In Great Britain, the whole thickness above the unfossiliferous bottom-rocks is about 70,000 feet. The thickness here given is the sum of the greatest thickness of each of the successive strata, and exceeds that existing at any one point, as one formation may be thickest in one district, and another in a district more or less remote.

3. The rocks of a country are to a great extent covered with earth or soil, so that they can be examined only at distant points.

4. The strata, in many regions, have been displaced, folded, fractured, faulted, and even crystallized extensively, adding greatly to the difficulties in the way of the geological explorer.

The following are the methods to be used in determining the true order of arrangement:—

A. In sections of the rocks exposed to view in the sides of valleys or ridges, the order should be directly studied, and each stratum traced, as far as possible, through all the exposed sections.

When, through large intervals, a covering of soil or water prevents the tracing of the beds, other means must be used.

B. The aspect or composition of the rock may help to determine which strata are identical. But this method should be used with caution, for the reason stated above, in § 1,—that rocks made at the very same time may be widely different; and, conversely, those made in very different periods may look precisely alike in color and texture.

C. Fossils afford the best means of determining identity. This is so because of the fact, already mentioned, that the fossils of an epoch are very similar in genera—if not in species—the world over; and those of different epochs are different.

As the kinds of fossils belonging to each period and age are now pretty well known, and catalogues and figures have been published, it is only necessary, on commencing the investigation of a stratum, to collect its fossils, study them with care, and then compare them with the figures and descriptions to be found in works on the subject. In this way it has been proved that the chalk formation exists in North America, although there is no chalk to be found. In the same manner the equivalents in America of the rocks of Britain and Europe, Asia, or even Australia, are ascertained; for this means of determination is a universal one, applying to the equivalency of rocks in different hemispheres as well as on the same continent.

REVIEW OF THE ANIMAL AND VEGETABLE KINGDOMS.

The following pages on the Animal and Vegetable Kingdoms are inserted in this place to prepare the student for the following portion of the work, on Historical Geology, in which the *progress of life* is a prominent part.

Distinctions between an Animal and a Plant.

1. *An Animal.*—An animal is a living being, sustained by nutriment taken into an internal cavity or *stomach*, through an opening called the *mouth*. It is capable of perceiving the existence of other objects, through one or more senses. It has (except in some of the lowest species) a head, which is the seat of the power of voluntary motion, and which contains the mouth. It is fundamentally a *fore-and-aft* structure, the head being the anterior extremity, and it is typically forward-moving. With its growth from the germ, there is an increase in mechanical power until the adult size is reached. In the processes of respiration and growth, it gives out carbonic acid, and uses oxygen.

A Plant.—A plant is a living being sustained by nutriment taken up externally by leaves and roots. It is incapable of perception, having no senses. It has no head, no power of voluntary motion, no mouth. It is fundamentally an *up-and-down* structure, and, with few exceptions, *fixed*. In its growth from the germ or seed, there is no increasing mechanical power. In the process of growth, it gives out oxygen and uses carbonic acid.

I. ANIMAL KINGDOM.

1. The Animal Structure.

The nature of an animal requires, for a full exhibition of its powers, the following parts:

1. A stomach and its appendages to turn the food into blood, with an arrangement for carrying off refuse material.
2. A system of vessels for carrying this blood throughout the body, so as to promote growth and a renewal of the structure.
3. A heart, or forcing-pump, to send the blood through the vessels.
4. A means of respiration, or of taking air into the system (as by lungs or gills), because this growth and renewal require the oxygen of the air to act in conjunction with the blood, as much as a fire requires air in order that the fuel may burn.
5. Muscles, or contractile fibres, to act by contraction and relaxation in putting the parts or members in motion.
6. A brain, or head-mass of nervous matter, and a system of nerves, branching through the body, to serve as a seat for the will and for the power of sensation and motion, and to convey the determinations of the will and sensation through the body.

In the lowest form of animal life, as some microscopic Protozoans, the stomach is not a permanent cavity, but is formed in the mass of the tissue whenever a particle of food comes in contact with the body. In other words, a stomach is extemporized as it is needed. In species of a little higher grade, as Polyps, there is a mouth and stomach, with muscles, an imperfect system of nerves when any, and a means of respiration through the general surface of the body; but there is no distinct heart, and the animal is ordinarily fixed to a support.

2. Subdivisions of the Animal Kingdom.

There are *four* distinct *plans of structure* according to which animals are made; and the species corresponding to each make up what is called a *sub-kingdom* in the kingdom of animals. These four sub-kingdoms, or plans of structure, are the following:—

1. The VERTEBRATE: having (as in Man, Quadrupeds, Birds, Reptiles, and Fishes) an internal jointed skeleton, of which the back-bone is called the *vertebral column*, and each of its joints a *vertebra*.

The remaining sub-kingdoms have *no internal jointed skeleton*.

2. The ARTICULATE: having (as in Insects, Spiders, Crabs, Lobsters, Worms) the body and its appendages (as the legs, etc.) articulated, that is, made up of a series of joints.

3. The MOLLUSCAN: having (as in the Oyster, Clam, Snail, Cuttle-fish) a soft, fleshy body without articulations or joints; and the appendages, when any exist, also without joints. The name is from the Latin *mollis, soft*.

4. The RADIATE: having (as in the Polyp, Medusa, Sea-urchin, Star-fish) the body, both externally and internally, radiate in arrangement, the parts being arranged radiately around the mouth and stomach,—as in a flower or an orange the parts are radiately arranged about its centre or central axis.

Radiate animals take after the vegetable kingdom in type of structure (plants also being *radiates*); yet they are strictly animals, as they have a mouth, stomach, and other animal organs. The type of structure in each of the other sub-kingdoms is purely animal.

5. PROTOZOANS.—Besides the above, there are other species of such extreme simplicity that neither of the systems of structure above mentioned is apparent in them, and these are, therefore, in a sense *systemless* animals. Many have not

even a mouth. They include the Sponges, and a large number of minute species, visible only with the aid of a microscope.

1. Sub-kingdom of Vertebrates.

Class 1.—Mammals.—Warm-blooded animals that suckle their young, as Man, Quadrupeds, Whales. Nearly all are viviparous; a few (as the Opossum and other *Marsupials*) are *semi-oviparous*, the young at birth being very immature.

Class 2.—Birds.—Warm-blooded air-breathing animals, oviparous, having a covering of feathers, and the anterior limbs more or less perfect wings.

Class 3.—Reptiles.—Cold-blooded air-breathing animals, oviparous, having a covering of scales or simply a naked skin. There are two sub-classes:—1. *True Reptiles* (as Crocodiles, Lizards, Turtles, Snakes), which breathe with lungs (or are air-breathing) when young as well as afterward, being, in this respect, like birds and quadrupeds; 2. *Amphibians* (as Frogs and Salamanders), which breathe by means of gills when young, and afterwards become air-breathing, the animal undergoing thus a metamorphosis.

Class 4.—Fishes.—Cold-blooded oviparous animals, breathing by means of gills, and having a covering of scales or simply a naked skin. There are three prominent groups:—

1. *Teliosts* (as the Perch, Salmon, and all common fishes), having the scales membranous, the skeleton bony, and the gills attached at only one margin.

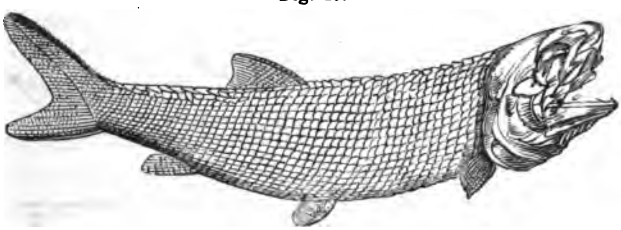
The name is from the Greek *teleios*, *perfect*, and *osteon*, *bone*, alluding to the skeleton being bony.

The scales in many are toothed or set with spines about the inner margin (fig. 50), while others have the margin smooth (fig. 49). Fishes having scales of the former kind, as the Perch, have been called *Ctenoids* by Agassiz (from the Greek *kteis*, *comb*); and those having scales of the latter kind, as the Salmon, etc., *Cycloids* (from the Greek *kuklon*, a *circle*).

2. *Ganoids* (as the Gar-pike and Sturgeon), having the scales bony and usually shining, and the skeleton often cartilaginous. The name is from the Greek *ganos*, *shining*.

Fig. 45 represents one of the ancient Ganoids. The vertebral column extends to the extremity of the tail, so that the tail-fin is *vertebrated*, while in modern Gars and Teliosts the

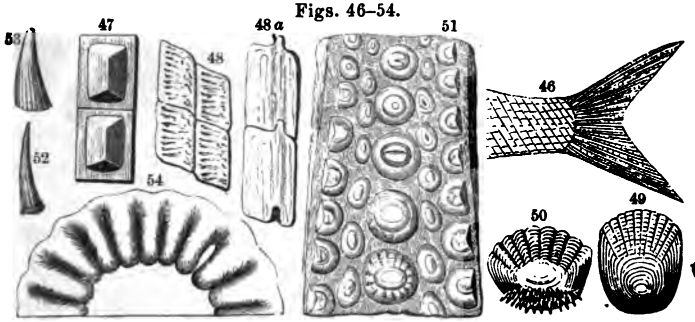
Fig. 45.



Palæoniscus Freieslebeni (× ⅓).

vertebral column stops at the commencement of the tail, or the tail-fin is non-vertebrate (fig. 46). Agassiz calls the former

Figs. 46–54.

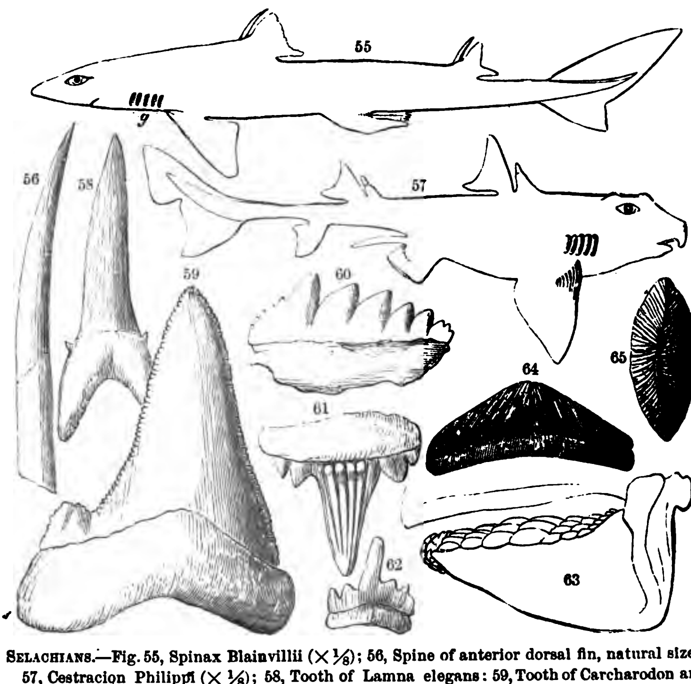


GANOIDS (excepting 49, 50).—Fig. 46, Tail of Thrissops (× ½); 47, Scales of Cheirolepis Traillii (× 12); 48, Palæoniscus lepidurus (× 6); 48 *a*, under-view of same; 49, Scale of a Cycloid; 50, id. of a Ctenoid; 51, Part of pavement-teeth of Gyrodus Umbilicus; 52, Tooth of Lepidosteus; 53, id. of a Cricodus; 54, Section of tooth of Lepidosteus osseus.

kind *heterocercal*, and the latter *homocercal*. The scales are either rhombic, as in figs. 45, 46, or rounded. Some of these rhombic bony scales are shown in figs. 47, 48. The teeth (figs. 52, 53) often have a folded or labyrinthine texture or arrangement within, as shown in fig. 54. In one group, the Ganoids have a pavement of teeth in the mouth, as in fig. 51.

3. *Selachians* (as the Sharks and Rays), having a hard skin, often rough with minute points, the skeleton more or

Figs. 55-65.



SELACHIANS.—Fig. 55, Spinax Blainvillii (× 1/8); 56, Spine of anterior dorsal fin, natural size; 57, Cestracion Philippi (× 1/8); 58, Tooth of Lamna elegans: 59, Tooth of Carcharodon angustidens; 60, Notidanus primigenius; 61, Hybodus minor; 62, Hyb. plicatilis; 63, Mouth of Cestracion, showing pavement-teeth of lower jaw; 64, Tooth of Acrodus minimus; 65, Tooth of Acrodus nobilis.

less completely cartilaginous, and the gills attached by both margins. The name is from the Greek *selachos*, *cartilage*.

Fig. 55 represents, much reduced, one of the order (a *Spinax*), having the mouth, as usual, on the under surface of the head, and remarkable for the spine before each of the back fins: one of the spines is shown, natural size, in fig. 56. Fig. 57 is an outline of another Selachian, of the genus *Cestracion*, living in the vicinity of Australia, peculiar in having the mouth at the extremity of the head, and also in the teeth of the mouth having in part the form and appearance of a pavement, as shown in fig. 63. Figs. 58 to 62 are teeth of different Selachians related to the Sharks; and figs. 64, 65, pavement-teeth of Cestraciont species. The Cestraciont Selachians were once very common; but now the only living species known are confined to Australasia.

2. Sub-kingdom of Articulates.

Among Articulates there are three *classes;* one, including the species adapted to live on land, and which, for this purpose, breathe by means of air-vessels branching through the body, and two,—of species adapted to live in water, and, therefore, having gills.

1. Land-Articulates, or the class of *Insecteans.* There are three orders or grand divisions of Insecteans: namely, 1. *Insects;* 2. *Spiders;* 3. *Myriapods* (or Centipedes).

2. Water-Articulates, including the two classes—1. *Crustaceans* (as Crabs, Lobsters, etc.), and 2. *Worms.*

Crustaceans.—A knowledge of the principal subdivisions of Crustaceans is especially important to the student in geology. There are three orders:—

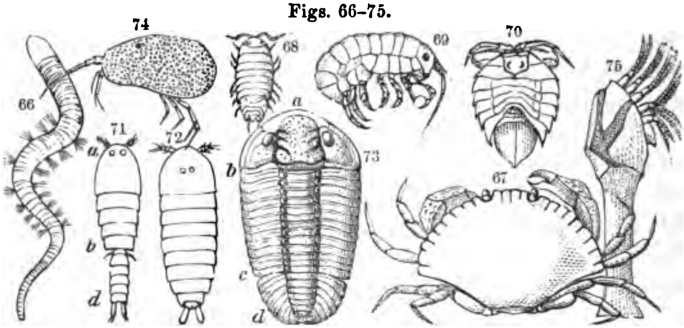
1. The *Decapods*, or 10-*footed* species, as the Crab (fig. 67), Lobster, Shrimp.

2. The *Tetradecapods*, or 14-*footed* species, as the *Sow-bug* (fig. 68), found in damp places under logs, the *Sand-flea* of sea-shores among drift sea-weed (fig. 69), etc.

3. The *Entomostracans*, or inferior species, having the feet defective, as the *Cyclops* and related species (figs. 71, 72),

Daphnia, *Limulus* or *Horse-shoe*, the *Cypris*, and other *Ostracoids* (fig. 74). These *Ostracoids* are generally minute spe-

Figs. 66–75.



Articulates.—1. ***Worms:*** **66, Arenicola piscatorum, or Lob-worm (× 1/6). 2.** ***Crustaceans:*** **67, Crab, species of Cancer; 68, an Isopod, species of Porcellio; 69, an Amphipod, species of Orchestia; 70, an Isopod, species of Serolis (× 1/2); 71, 72, Sapphirina Iris; 71, female, 72, male (× 6); 73, Trilobite, Calymene Blumenbachii; 74, Cythere Americana, of the Ostracoid family (× 12); 75, Anatifa, of the Cirriped tribe.**

cies, having a shell like that of a bivalve Mollusk, as fig. 74 shows; but inside of the shell, instead of an animal like a clam, there is one more like a shrimp, with jointed legs. The name is from the Greek *ostrakon*, *shell*, the word from which oyster is derived.

Among *Entomostracans*, there are also the Barnacles and other Cirripeds, one of which is represented in fig. 75.

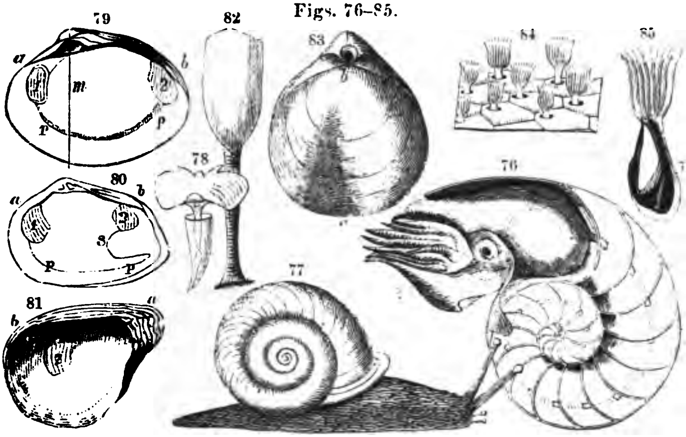
Trilobites (fig. 73) are Crustaceans related to the Entomostracans, though more like the Tetradecapods (figs. 68, 70) in form. They may be intermediate between the two orders. The tribe is now extinct.

3. Sub-kingdom of Mollusks.

There are two grand divisions or classes of Mollusks:—1. The *Ordinary Mollusks*, as the *Clam*, *Snail*, and *Cuttlefish;* and, 2, the plant-like or *Anthoid* Mollusks, many of which are attached by stems, like flowers, and some have an external resemblance to flowers (figs. 84, 85), though *not radiate internally* like true Radiate animals.

1. **Ordinary Mollusks.**—There are three orders:—1. *Cephalopods:* having the head surrounded by arms, and large eyes; the shell, when any exists as an *external* covering for the body, is, with a rare exception, divided internally by

Figs. 76–85.



MOLLUSKS.—1. *Cephalopods:* fig. 76, Nautilus, showing the partitions in the shell and the animal in the outer chamber.—2. *Gasteropods:* 77, Helix.—3. *Pteropods:* 78, Cleodora.—4. *Conchifers:* 79, 80; 81, the oyster.—5. *Brachiopods:* 82, Lingula, on its stem; 83, Terebratula, showing the aperture from which the stem for attachment passes out.—6. *Bryozoans:* 84, Eschara, with the animals a little enlarged; 85, one of the animals out of the shell, more enlarged.

cross-partitions into a series of chambers, whence they are called *chambered* shells, as in the Nautilus (fig. 76) and Ammonite (fig. 282). A few have an *internal* chambered shell; others an *internal* straight bone, which has sometimes a conical cavity. The name is from the Greek *kephale, head*, and *pous, foot*.

2. *Cephalates:* having a head with distinct eyes, but no arms around it, and usually a spiral shell, if any; as the Snail (fig. 77) and other *Univalves*. The name is from the

Greek *kephale, head.* The species of one division—that containing the Snail and all ordinary Univalves—are called *Gasteropods,* from the Greek, implying that they crawl on their belly,—this part acting, therefore, as a *foot.* In another division, they have a pair of wing-like oars for swimming, and these are called *Pteropods* (fig. 78), from the Greek *pteron, wing,* and *pous, foot.*

3. *Acephals:* having no prominent head, and only imperfect eyes if any; and the shell commonly of two parts called valves, whence the common name of most of the species, *Bivalves,* as the *oyster, clam* (figs. 79–81). These species are called *Conchifers,* from the Latin *concha, shell,* and *fero, I bear.* They have thin lamellar gills either side of the body, whence they are often called also *Lamellibranchs,* from *lamella, a plate,* and *branchia, a gill.*

In fig. 79, showing the inside of a valve, 1, 2 are impressions of the two great muscles by which the animal closes the shell, and *p p* is the impression of the margin of the mantle or pallium, and called the pallial impression. This mantle is a thin membrane lying next to the shell; the gills are between it and the body of the Mollusk. In fig. 80, the pallial impression *p p* has a deep bend or sinus opening towards the back margin of the valve. Shells having this sinus in the impression are described as *sinupallial,* and those without it as *integripallial.* In fig. 81, of the oyster, there is but one large muscular impression (at 2).

2. **Anthoid Mollusks.**—These are of three orders:—

1. *Brachiopods:* species (figs. 82, 83) having a bivalve shell, like the Conchifers, but one whose form is symmetrical either side of a middle line; that is, if a line be dropped from the beak to the opposite edge (as from *b* to *a* in fig. 83), the parts of the shell on the two sides of the line will be equal. A line similarly drawn in the Conchifers divides the valve unequally (as in fig. 79). The animals have two spiral arms within, which serve as gills. The name

Brachiopod, from the Greek *brachion*, *arm*, and *pous*, *foot*, refers to these arms.

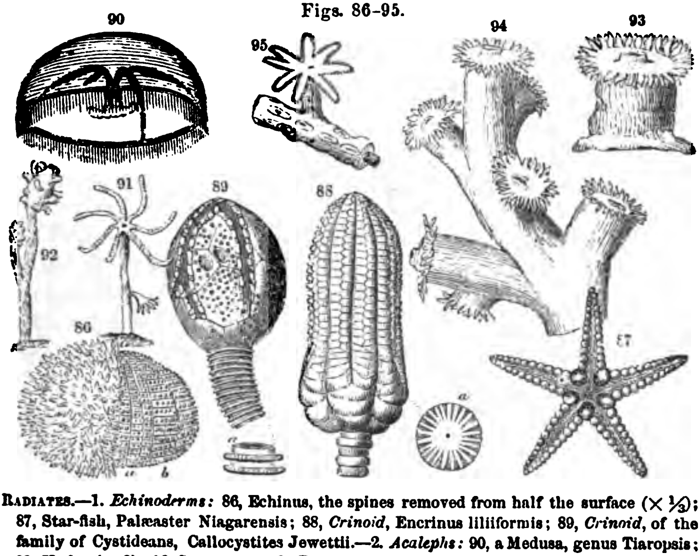
2. *Ascidians:* species with a leathery or fleshy exterior, and no shell, and hence hardly recognized among fossils.

3. *Bryozoans:* species of minute size, making often cellular corals which, though often in thin plates or incrustations, sometimes delicately branch like a moss, whence the name, from the Greek *bruon*, *moss*, and *zōon*, *animal*. They include the *Cellepores*, *Flustras*, etc.

4. Sub-kingdom of Radiates.

There are three grand divisions of Radiates:—

Figs. 86-95.



RADIATES.—1. *Echinoderms:* 86, Echinus, the spines removed from half the surface (× ⅓); 87, Star-fish, Palæaster Niagarensis; 88, *Crinoid*, Encrinus liliiformis; 89, *Crinoid*, of the family of Cystideans, Callocystites Jewettii.—2. *Acalephs:* 90, a Medusa, genus Tiaropsis; 91, Hydra (× 8); 92, Syncoryna.—3. *Polyps:* Fig. 93, an Actinia; 94, a coral, Dendrophyllia; 95, part of a branch of a coral of the genus Gorgonia, showing one of the polyps expanded.

1. **Echinoderms** (figs. 86–89): having a more or less hard exterior, which is often covered with spines—whence the

name, from *echinus, a hedgehog*, and *derma, skin*. The mouth opens downward in all species except the Crinoids. Among them there are—(1) *Echinoids*, in which the exterior is a solid shell covered with spines, and the mouth opens downward (fig. 86—the spines are removed from half of the shell); (2) The *Asterioids*, or *Star-fishes*, in which the exterior is rather stiff, but still flexible, so that the animal flexes it in its movements (fig. 87); (3) *Crinoids*, which are much like Star-fishes, but have a stem like a flower (figs. 88, 89).

2. **Acalephs** (figs. 90–92): having a soft, flexible body, usually of a jelly-like aspect, though rather tough, and moving, when free, with the mouth downward, as the *Medusæ* (fig. 90). Some of the species called *Hydroid* Acalephs (figs. 91, 92), in one of their stages, if not through all, look like Polyps; and some of these Acalephs form corals, like the Polyps. The other species are too soft to be common as fossils.

3. **Polyps** (figs. 93–95): having a soft body usually attached to a support; a mouth opening upward; one or more rows of tentacles arranged about the margin of a disk (somewhat like the petals of an Aster around its central disk); and the mouth situated at the centre of the disk, as in fig. 93. Most corals are made by Polyps. The coral is secreted *within* the polyp in the same manner as bones are secreted within other animals. Figs. 94, 95 represent portions of living corals with the polyps expanded. The number of rays in the cells of modern corals—called *Actinoids*—is a multiple of *six;* and that in the more ancient corals, called *Cyathophylloids*, is a multiple of *four*.

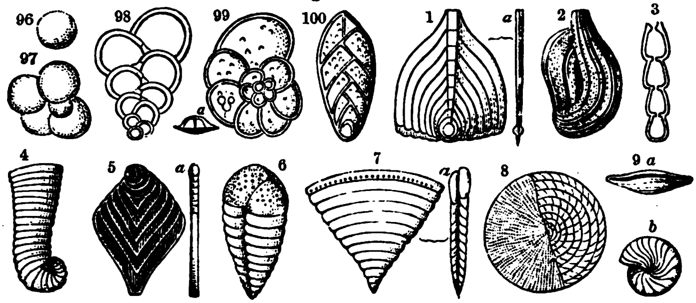
5. Protozoans.

The principal groups of *Protozoans* important to the geologist are three :—

1. The *Sponges*. The sponges contain in their tissues great numbers of minute spicules, which are, in nearly all species, *siliceous;* and these siliceous spicules are found fossil.

2. The *Rhizopods*, which make minute *calcareous* shells consisting usually of many combined cells. They are often called *Polythalamia*, from their *many cells*, and *Foraminifera*, from the existence of minute perforations through the shells. Some of the species, magnified from 10 to 20 times (excepting the last two, which are natural size), are represented in figs. 96–109.

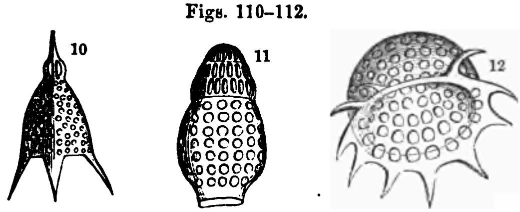
Figs. 96–109.



Rhizopods.—Fig. 96, Orbulina universa; 97, Globigerina rubra; 98, Textilaria globulosa *Ehr.*; 99, Rotalia globulosa; 99 *a*, Side-view of Rotalia Boucana; 100, Grammostomum phyllodes *Ehr.*; 101, Frondicularia annularis; 102, Triloculina Josephina; 103, Nodosaria vulgaris; 104, Lituola nautiloides; 105, *a*, Flabellina rugosa; 106, Chrysalidina gradata; 107, *a*, Cuneolina Pavonia; 108, Nummulites nummularia; 109 *a*, *b*, Fusulina cylindrica.

3. *Polycystines*, which make minute *siliceous* shells, consisting of many united cells (figs. 110–112). They differ

Figs. 110–112.



Polycystines.—Fig. 110, Lychnocanium Lucerna (× 100); 111, Eucyrtidium Mongolfieri (× 100); 112, Halicalyptra fimbriata (× 75).

from the Rhizopods, further, in having the arrangement of the cells *radiate*, and not *spiral* or *alternate*.

II. VEGETABLE KINGDOM.

The vegetable kingdom is not divisible into sub-kingdoms like the animal; for all the species belong to one grand type, the Radiate, the one which is the lowest of those in the animal kingdom. The higher subdivisions are as follow:—

I. CRYPTOGAMS.—Having no distinct flowers or proper fruit, the so-called seed being only a spore, that is, a simple cellule without the store of nutriment (albumen and starch) around it which makes up a true seed; as Ferns, Sea-weed. They include—

1. *Thallogens.*—Consisting wholly of cellular tissue; growing in fronds without stems, and in other spreading forms; as (1) Algæ, which include Sea-weeds and also the Confervæ or frog-spittle, and many allied fresh-water plants; (2) Lichens, the dry grayish-white and grayish-green plants that cover stones, logs, &c.

The *Marine Algæ*, or *Sea-weeds*, that are found fossil, and are not microscopic in size, are mostly of the tough leathery kinds, related to the modern Fuci. They are often called by the general term of *Fucoids*, signifying *resembling Fuci.*

2. *Anogens.*—Consisting wholly of cellular tissue; growing up in short, leafy stems; as (1) Musci, or Mosses; (2) Liverworts.

3. *Acrogens.*—Consisting of vascular tissue in part, and growing upward; as (1) Ferns or Brakes; (2) Lycopodia (Ground-Pine); (3) Equiseta (Horse-tail or Scouring Rush); and including many genera of trees of the Coal period related to these groups.

The Microscopic Algæ are sometimes called *Protophytes.* They are mostly one-celled species: a few consist of a small number of cells united; and these pass into other species, like common *mould*, which are in threads, simple or branched, made up of many cells. The kinds found fossil are the following:—

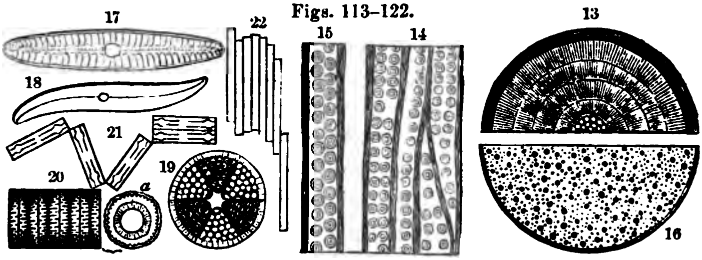
1. *Diatoms.*—Species having a siliceous shell, often quite beautiful in form. Some of the shells are represented, highly magnified, in figs. 117 to 122. They grow so abundantly in some waters, fresh or salt, as to produce large siliceous beds, the material of which is an excellent polishing powder and has long been used for this purpose.

2. *Desmids.*—Species making no siliceous shell, consisting of one or more greenish cells (figs. 181 to 187, p. 110). These are found fossil in flint and hornstone.

II. PHENOGAMS.—Having (as the name implies) distinct flowers and seed; as the *Pines*, *Maple*, and all our shade and fruit trees, and the plants of our gardens. They are divided into—

1. *Gymnosperms.*—Having the flowers exceedingly simple, and the *seed naked*,—the seed being ordinarily on the inner surface of the scales of cones, and the wood having a bark and rings of annual growth (fig. 113); as the *Pine*, *Spruce*, *Hemlock*, etc. The name Gymnosperm is from the Greek for *naked seed.*

Figs. 113–122.



PLANTS.—Fig. 113, section of exogenous wood; 114, fibres of ordinary coniferous wood (Pinus Strobus), longitudinal section, showing dots, magnified 300 times; 115, same of the Australian conifer, Araucaria Cunninghami; 116, section of endogenous stem.

Figs. 117 to 122, DIATOMS highly magnified; 117, Pinnularia peregrina, Richmond, Va.; 118, Pleurosigma angulatum, id.; 119, Actinoptychus senarius, id.; 120, Melosira sulcata, id; a, transverse section of the same; 121, Grammatophora marina, from the salt water at Stonington, Conn.; 122, Bacillaria paradoxa, West Point.

The Gymnosperms include (1) the *Conifers*, or the Pine-tribe of plants, usually called evergreens; and (2) the *Cycads*, or plants related to the *Cycas* and *Zamia*, which have the leaves and look of a Palm page 167), although, in fruit and wood, true Gymnosperms. There is a third group of extinct species (which have not existed since the Carboniferous age), called *Sigillariæ* (see p. 128).

The wood of the Conifers is simply woody fibre without ducts, and in this respect, as well as in the flowers and seed, this tribe shows its inferiority to the following subdivision. The fibres, moreover, may be distinguished, even in petrified specimens, by the dots along their surface as seen under a high magnifier. The dots look like holes, though really only thinner spaces. Fig. 114 shows these dots in the *Pinus Strobus.* In other species they are less crowded. In one division of the Conifers, called the *Araucariæ*, of much geological interest, these dots on a fibre are alternated (fig. 115), and the Araucarian Conifers may thus be distinguished.

2. *Angiosperms.*—Having regular flowers and *covered seed;* growth exogenous, the plants having a bark and rings of annual growth (fig. 113); as the *Maple*, *Elm*, *Apple*, *Rose*, and most of the ordinary shrubs and trees. These plants are called *Angiosperms*, because the seeds are *in seed-vessels;* and also *Dicotyledons*, because the seed has two cotyledons or lobes.

The Gymnosperms and Angiosperms make up the division of plants called *Exogens*, which is so named from the Greek *exō*, *outward*, and *gennaō*, *to grow*, because growth takes place through annual additions of layers to the *outside* of the trunk between the wood and the bark, as illustrated in fig. 113.

3 *Endogens.*—Having regular flowers and seed; growth *endogenous*, the plants being without bark, and showing, in a transverse section of a trunk, the ends of fibres, and no rings of growth (fig. 116); as the *Palms*, *Rattan*, *Reed*, *Grasses*, *Indian Corn*, *Lily*. The Endogens are *Monocotyledons;* that is, the seed is undivided, or consists of but one cotyledon.

PART III.

HISTORICAL GEOLOGY.

Historical Geology treats of the order of succession in the strata of the earth's crust, and of the changes that were going on during the formation of each bed or stratum,—that is, of the changes in the oceans and the land; of the changes in the atmosphere and climate; of the changes in the plants and animals. In other words, it is a historical view of the events that took place during the earth's progress, derived from the study of the successive rocks. It is sometimes called *stratigraphical* geology; but this term embraces only *a description of the nature and arrangement of the earth's strata.*

By using the means for determining the order of the several formations mentioned on page 44, and by a careful study of the organic remains (as fossils are often called) contained in the rocks, from the oldest to the most recent, it has been found that a number of great *ages* in the progress of this life, and in other events of the history, can be made out.

The following have thus been ascertained:

(1.) There was *first* an age, or division of time, when there was no life on the globe; or, if any existed, this was true only in the later part of the age, and the life was probably of the very simplest kinds.

(2.) There was next an age when Shells or Mollusks, Corals, Crinoids, and Trilobites, abounded in the oceans, when the continents were almost all beneath the salt waters, and when there was, as far as has been ascertained, no terrestrial life.

(3.) There was next an age when, besides Shells, Corals, Crinoids, Trilobites, and Worms, there were Fishes in the waters, and when the lands, though yet small, began to be covered with vegetation.

(4.) There was next an age when the continents were at many successive times largely dry or marshy land, and the land was densely overgrown with trees, shrubs, and smaller plants, of the remains of which plants the great coal-beds were made. In animal life there were, besides the kinds already mentioned, various Amphibians and some other Reptiles of inferior tribes.

(5.) There was next an age when Reptiles were exceedingly abundant, far outnumbering and exceeding in variety, and many also in size and even in rank, those of the present day.

(6.) There was next an age when the Reptiles had dwindled, and Mammals or Quadrupeds were in great numbers over the continents; and the size of these Quadrupeds, like that of the Reptiles in the preceding age, was far greater than the size of modern species.

(7.) After this came Man; and the progress of life here ended.

The above-mentioned ages in the progress of life and the earth's history have received the following names:—

1. AZOIC TIME OR AGE.—The name is from the Greek *a*, *not* or *without*, and *zōe*, *life*.
2. AGE OF MOLLUSKS, or the SILURIAN AGE.
3. AGE OF FISHES, or the DEVONIAN AGE.
4. AGE OF COAL-PLANTS, or the CARBONIFEROUS AGE.
5. AGE OF REPTILES, or the REPTILIAN AGE.
6. AGE OF MAMMALS, or the MAMMALIAN AGE.
7. AGE OF MAN.

The first of these ages—the *Azoic*—stands apart as the preparatory time for the commencement of the systems of life. The next three ages were alike in many respects,—especially in the air of antiquity pervading the tribes that then lived, the shells, crinoids, corals, fishes, coal-plants, and reptiles belonging to tribes that are now wholly or nearly extinct. The era of these ages has, therefore, been appropriately called *Paleozoic time*, the word *Paleozoic* coming from the Greek *palaios*, *ancient*, and *zōe*, *life*.

The next age was ushered in after the extinction of many of the Paleozoic tribes; and its own peculiar life approximated more to that of the existing world. Yet it was still made up wholly of extinct species, and the most prominent of the tribes and genera disappeared before or at its close. This age corresponds to *Medieval* time in geological history, and is called *Mesozoic time*, from the Greek *mesos*, *middle*, and *zōe*, *life*.

The next age was decidedly modern in the aspect of its species, the higher as well as lower, although only a few of those of its later epochs survive into the age of Man. It is called *Cenozoic time*, from the Greek *kainos*, *recent*, and *zōe*, *life* (the *ai* of Greek words always becoming *e* in English,—as, for example, in *ether*, from the Greek *aither*).

The following are, then, the grand divisions of geological time adopted:—

I. Azoic Time.

II. Paleozoic Time, including (1) The Age of Mollusks, or Silurian; (2) The Age of Fishes, or Devonian; (3) The Age of Coal-Plants, or Carboniferous.

III. Mesozoic Time, including the Reptilian Age.

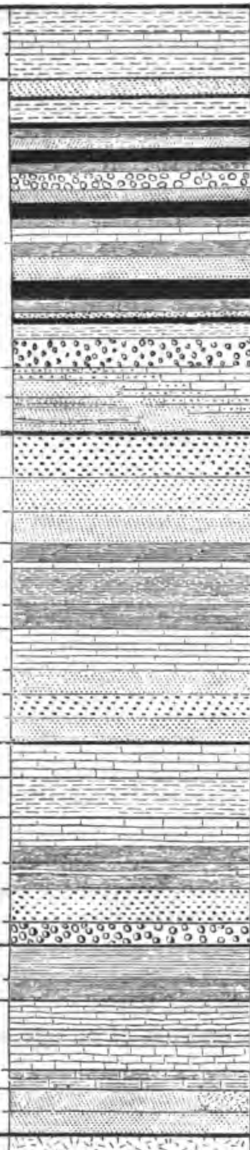
IV. Cenozoic Time, including the Mammalian Age.

V. The Age of Mind, or the Human Era.

The following sections represent the successive formations of the globe, arranged in the order of time, with the subdivisions corresponding to the Ages and Periods.

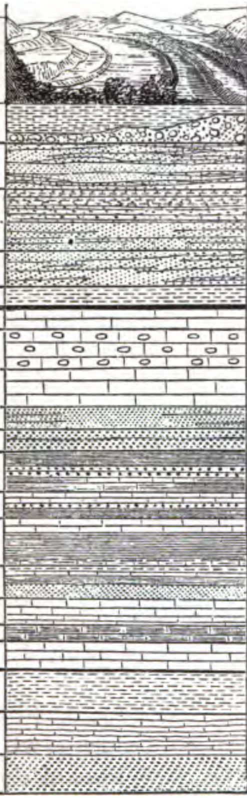
The various strata in the formations of an age are very

Fig. 123—*Paleozoic.*



Ages.		*American Periods.*	*Foreign Divisions.*
Carboniferous Age, or Age of Coal Plants.		15 Permian.	**Permian.**
		14 Carboniferous, or Coal Measures.	**Carboniferous, or Coal Measures.**
		13 Sub-carboniferous.	**Mountain limestone.**
Devonian Age, or Age of Fishes.		12 Catskill.	**Old Red Sandstone.**
		11 Chemung.	
		10 Hamilton.	
		9 Corniferous.	
		8 Oriskany.	
Silurian Age, or Age of Mollusks.	Upper.	7 Lower Helderberg.	**Ludlow beds.**
		6 Salina.	
		5 Niagara.	**Wenlock beds.**
	Lower.	4 Hudson.	**Caradoc sandstone.**
		3 Trenton.	**Bala limestone.** **Llandeilo flags.**
		2 Potsdam, or Primordial.	**Primordial.**
Azoic.		1 Azoic.	**Azoic.**

Fig. 123 (*continued*).



Ages.	*Periods.*	*Foreign Subdivisions.*
Age of Man.		
Age of Mammals, or Cenozoic Time.	Post-tertiary.	Quarternary, or Pleistocene.
	Tertiary.	Pliocene. Miocene. Eocene.
Age of Reptiles, or Mesozoic Time.	Cretaceous.	Upper Cretaceous. Middle Cretaceous. Lower Cretaceous.
	Jurassic.	Wealden. Oolite. Lias.
	Triassic.	Keuper. Muschelkalk. Bunter-sandstein.

diversified in character, limestones being overlaid abruptly by sandstones, conglomerates, or shales, or either of these last by limestones; and each may be very different from the following in its fossils. These abrupt transitions in the strata are proofs that there were great changes at times in the conditions of the region where the strata were formed, and the transitions in the kinds of fossils are evidence of great destruction at intervals in the life of the seas. Such transitions, therefore, naturally divide off the ages into smaller portions of time, or *periods*, as they are called. By transitions similar in kind, but not so great, *periods* may often be subdivided into still smaller parts, or *epochs*.

In the preceding sections, Azoic is at the bottom, on the left; above it there are the names *Silurian*, *Devonian*, and so on; and the names of the Periods, *Potsdam*, *Trenton*, etc., dividing off these Ages, on the right.

The names of the Periods in the first part of the section (those of the *Paleozoic*) are derived from the names of American rocks. The names on the other part are mostly European, as the series of rocks it contains (those of *Mesozoic* and *Cenozoic* time) are more complete in Europe than in America.

The map on page 69 represents the distribution of the rocks of the different ages, as surface-rocks, over the United States and Canada.

The *Azoic* areas are dotted with short lines.

The *Silurian* are lined horizontally.

The *Devonian* are lined vertically.

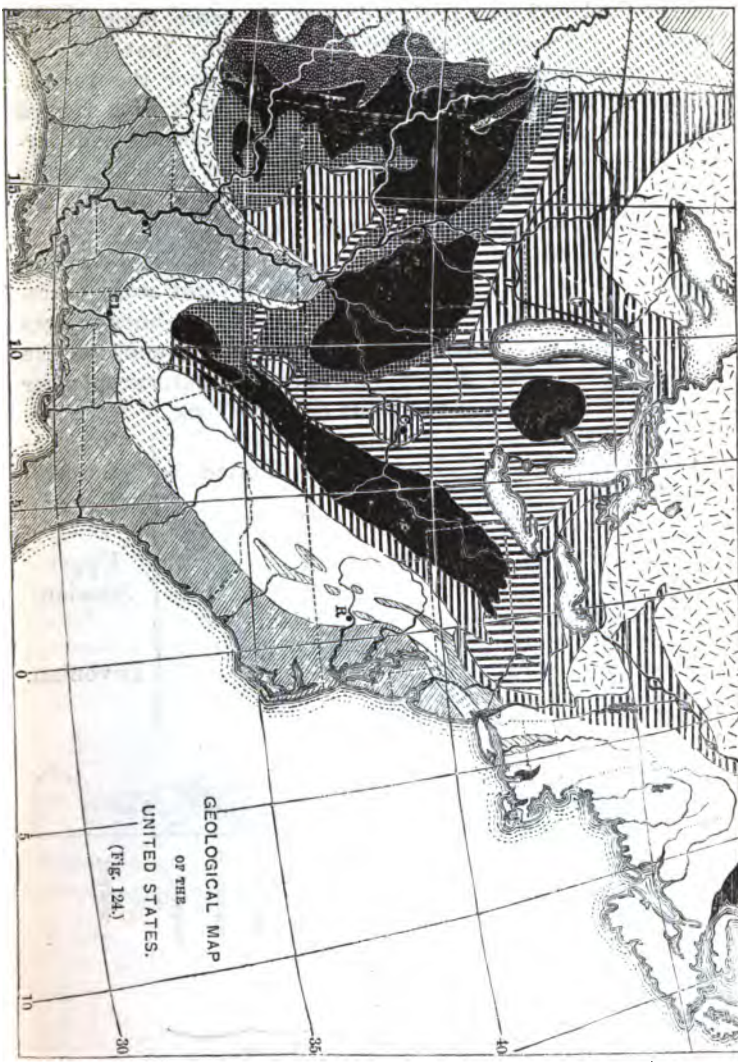
The *Carboniferous* are black, or black cross-lined or dotted with white, the black areas being of the *Carboniferous* period; the cross-lined of the *Subcarboniferous;* the dotted, of the *Permian.*

The *Mesozoic* have lines, or lines of dots, inclined from the right above to the left below, thus (/); the areas with lines being *Triassic* or *Jurassic*, and those with lines of dots *Cretaceous.*

The *Cenozoic* have lines inclined from the left above to the right below, thus (\); the areas more openly lined on the left border of the map are of fresh-water or brackish-water origin, and the rest mainly of marine origin.

The areas left white are of unascertained or doubtful age.

The Silurian strata may underlie the Devonian, and both Silurian and Devonian the Carboniferous. The black areas



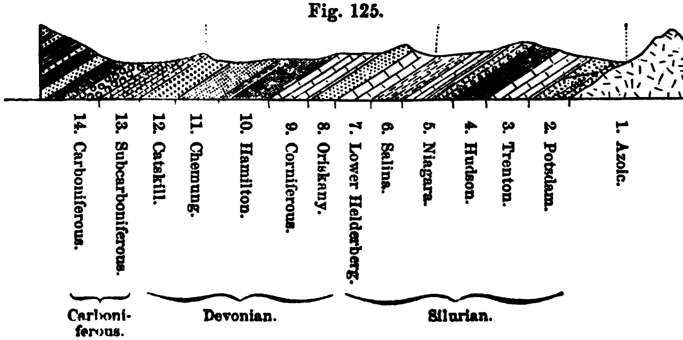
GEOLOGICAL MAP OF THE UNITED STATES.
(Fig. 124.)

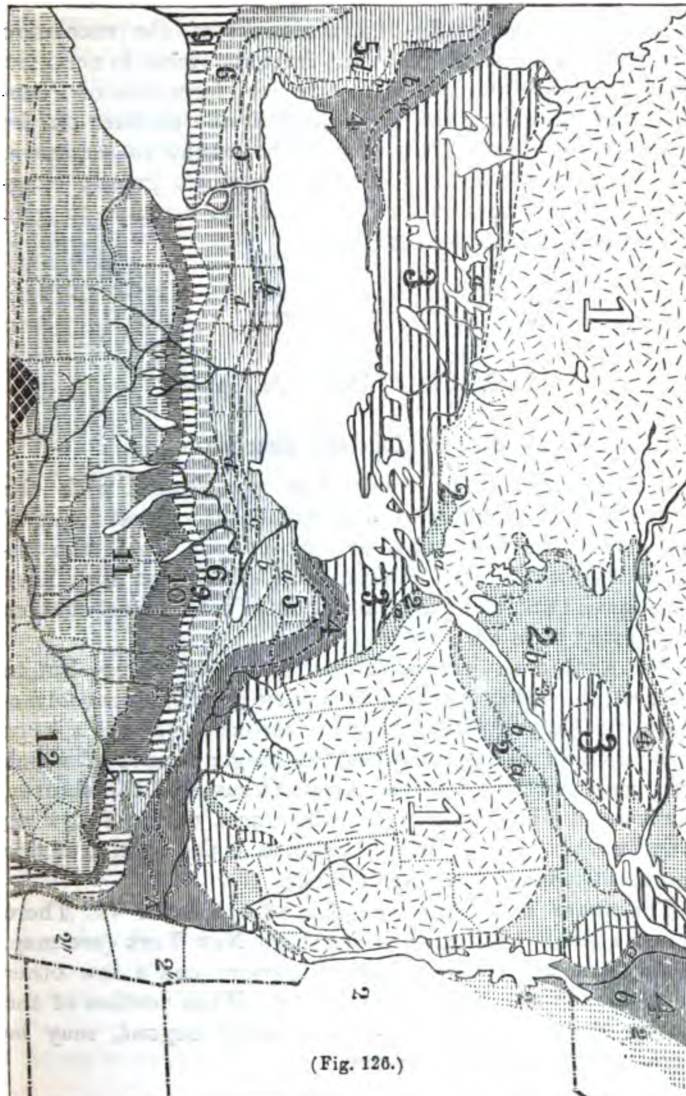
of the Carboniferous period do not, therefore, indicate the absence of Devonian and Silurian, but only that the Carboniferous strata are the *surface* strata over the region. There may even be exceptions to this remark with regard to the *surface* strata; for over the areas thus marked Carboniferous, older rocks may occur in some of the bluffs along the valleys, or occupy small areas in the region, which are too limited to be noted on so small a map.

The map on page 71 represents the surface-rocks of the State of New York and Canada, the several areas corresponding to the *periods*. For the Silurian, the lines or dots are drawn *horizontally*, as in the preceding, and for the Devonian, *vertically*. There is no Carboniferous, except near the southern border of the State of New York.

No. 1. The Azoic. 2. The Primordial, or Potsdam Period. 3. The Trenton Period. 4. The Hudson Period.	Lower Silurian.
5. The Niagara Period. 6. The Salina Period.	Upper Silurian.
9. The Upper Helderberg Period. 10 The Hamilton Period. 11 The Chemung Period. 12. The Catskill Period.	Devonian.

Fig. 125.





(Fig. 126.)

Geological Map of New York and Canada.

In the section in fig. 125, the rocks of the successive periods are represented in order, from the Azoic, in northern New York, southwestward to the Coal formation of Pennsylvania, showing that they succeed one another on the map simply because *they come to the surface in succession.* The amount of dip and its regularity are greatly exaggerated in the section; and there is no attempt to give the relative thickness of the beds.

I. AZOIC TIME, OR AGE.

1. Rocks: kinds and distribution.

1. *Distribution.*—The Azoic Age commenced with the origin of the earth's crust, and includes the oldest rocks of the globe. Its formations are those upon which the fossiliferous rocks of the Silurian and subsequent ages have been spread out, and the material out of which most of these later rocks have been made.

The Azoic rocks extend around the whole sphere; but, in general, they are concealed from view by subsequent formations. In North America they are *surface* rocks over a large area north of the great lakes, the longer branch of which area runs northwest to the Arctic Ocean, and the shorter, northeast to Labrador. The white area on the following map, in what is now British America, is the portion of the continent covered with Azoic rocks.

The shape is a little like that of the letter V. There is also a small Azoic area in northern New York (see map, p. 71); another south of Lake Superior; and a few other spots east of the Rocky Mountains. What portion of the Rocky Mountain region, or the country beyond, may be Azoic at surface, is not known.

In Europe, Azoic rocks are in view in the great iron regions of Sweden and Norway, in Bohemia, and in northern Scotland.

2. *Kinds of Rocks.*—The rocks are mostly *crystalline* rocks, such as granite, syenite, gneiss, hornblendic gneiss, mica-

Fig. 127.

Azoic Map of North America.

schist, hornblendic, chloritic, and talcose schists, and granular limestone. But besides these there are some hard conglomerates, quartz-rocks or gritty sandstones, and slates. The beautiful iridescent feldspar called *labradorite* is a common constituent of some of the crystalline or granitic rocks.

Along with the rocks there are, in some regions, immense beds of *iron ore* (*i*, *i*, *i* in fig. 128). In northern New York there are beds 100 to 700 feet thick. In Missouri there are two "iron mountains," as they are called; one, the Pilot Knob, is 581 feet high, the other 228 feet. Similar iron-ore beds occur in Michigan, south of Lake Superior.

Fig. 128.

3. *Disturbance and Crystallization of the Rocks.*—The layers of gneiss and other schistose rocks, with the included limestones, are nowhere horizontal; but, instead of this, they dip at all angles, and are often flexed or folded in a most complex manner. Fig. 129 represents the folded character

Fig. 129.

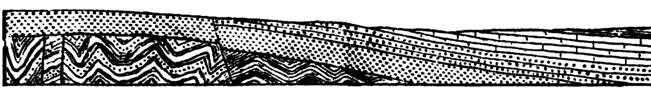


Fig. 129, by Logan, from the south side of the St. Lawrence in Canada, between Cascade Point and St. Louis Rapids; 1, gneiss.

of the Azoic rocks of Canada. The folded rocks in this figure are overlaid by beds that are nearly horizontal, which belong to the Lower Silurian.

Owing to the dislocations and uplifts which the rocks have undergone, the iron-ore beds look like veins; and even the strata of crystalline limestone have often a similar vein-like appearance. Where strata have been thrown up so that the layers stand vertical, the included bed of ore will be vertical also, and will descend downward in the same manner as a true metallic vein; and through the breaking and faulting of the strata, many of those irregularities would result that are so common in veins.

Gneiss, mica-schist, granular limestone, and other crystalline rocks have been described on page 23 as *metamorphic* rocks,—rocks that were once horizontal sandstones, shales, and stratified limestones, and which have been, by some process, *crystallized.* The gneiss and schists in Azoic regions are actually in layers or strata, alternating with one another, as common with ordinary sandstones and shales; and the ore-beds are conformable to the layers of schist and quartz-rock in which they occur.

4. *Conclusions as to the Origin of the Rocks.*—The following conclusions hence follow:—(1) That the Azoic rocks here referred to were originally horizontal strata of sandstones, shales, and limestones; (2) That after their formation they were pushed out of place by some great movement of the earth's crust, which uplifted and folded them, so that now they are nowhere horizontal; (3) That, besides being displaced, they were also crystallized,—that is, changed into *metamorphic* rocks. Even the sandstones and conglomerates of the Azoic give evidence by their hardness of the action of the same heat that caused the crystallization of other Azoic strata.

It is altogether probable that the time of the uplifting and that of the metamorphism were the same. There may have been many such metarmophic epochs in the course of the Azoic age. But, since even the latest beds of the Azoic are thus upturned and crystallized, an extensive revolution of this kind must have been a closing event of the age. Fig. 129 shows that the upturning preceded the formation of the lowest Silurian beds, for these lie undisturbed over the folded and crystallized Azoic.

Below the surface Azoic rocks, there must be others, constituting the *interior portions of the earth's crust.* If the earth were originally a melted globe, as appears altogether probable, the earth's crust is its cooled exterior. Whenever the crust formed, its surface must have been at once worn by the waves, wherever within their reach, and deposits of sand, pebbles, and clay must have been formed; and in this way the Azoic formations were begun. But at the same time that these surface strata were in progress, the crust would have been increasing in thickness within by the cooling which was continuing its progress. Of the *interior* rock of the crust we know little or nothing.

2. Life.

The Azoic rocks as far as they have been examined, contain no fossils. It is not yet certain, however, that some life may not have existed on the globe before the close of the age.

There is abundant reason for concluding that *if there were any plants*, they were only *sea-weeds;* for none but sea-weeds occur in the overlying Lower Silurian formations. *If there were any animal life*, it is probable that it included only the minute animalcular forms; since if shells and corals were in the seas their remains would have been preserved in some of the beds that were least altered by the heat of metamorphism.

The *graphite* in certain Azoic rocks, as in those near Ticonderoga, is sometimes thought to be evidence of the existence of plants, because it is known that in later times graphite has been formed out of the remains of plants. The limestone beds have suggested the idea that there may have been animal life of some kinds; for almost all limestones (see p. 21) are of *organic* origin. But the evidence with regard to both plants and animals is still doubtful.

3. General Observations.

The large Azoic area on the map, p. 73, represents the main portion of the dry land of North America in the later part or at the close of the Azoic age; for it consists of the rocks made during the age, and is bordered, on its different sides, by the earliest rocks of the next age. It is the outline, approximately, of *Azoic North America*, or the continent, as it appeared when the Silurian age opened. It is, therefore, the beginning of the dry land of North America, the original nucleus of the continent, to which additions were made, in succession, with the progress of the ages, until its final completion as the age of Man was opening. The smaller Azoic areas mentioned appear to have been mere islets in the great continental sea.

Each of the other continents was probably represented at the same time by its spot, or spots, of dry land. All the rest of the sphere, excepting these limited areas, was an expanse of waters.

The evidence appears also to show that both waters and land were lifeless wastes, except it be that sea-weeds and Protozoans were in the oceans.

The facts to be presented under the Silurian age teach that the great, yet unmade, continents, although so small in the amount of dry land, were not covered by the *deep* ocean, but only by *shallow* oceanic waters. They lay just beneath the waves, already outlined, prepared to commence that series of formations—the Silurian, Devonian, Carboniferous, and others—which was required to finish the crust for its ultimate continental purposes.

We thus gather some hints with regard to the geography of America in the period of its first beginnings. It is stated, in Genesis, that on the third day the *waters were gathered together into one place, and the dry land was made to appear*, and also that, as a second work of the same day, *plants were called into existence* as the *first life* of the earth. The Azoic age in geology witnessed, with little doubt, the appearance of the first continents and probably of the first plants.

The outline of the northern Azoic area on the map, p. 73 —the embryo of the continent—is *very nearly parallel* to that of the present continent. The Azoic lands, both in North America and Europe, are largest in the more northern latitudes.

II. PALEOZOIC TIME.

PALEOZOIC time includes three ages:—

1. The AGE OF MOLLUSKS, or SILURIAN AGE.
2. The AGE OF FISHES, or DEVONIAN AGE.
3. The AGE OF COAL-PLANTS, or CARBONIFEROUS AGE.

In describing the rocks of these ages over North America, and the events connected with their history, there are *three distinct regions* to be noted,—distinct, because in an important degree independent in their history. These are—

1. The *Eastern border region*, or that near the Atlantic border, including central and eastern New England, New Brunswick and Nova Scotia, and the coast region south of New York.

2. The *Appalachian region*, or that now occupied by the Appalachian Mountain chain, from Labrador, on the north, along by the Green Mountains, and the continuation of the heights through New Jersey, Pennsylvania, Virginia, eastern Tennessee, and so southwestward to Alabama.

3. The *Interior Continental region*, or that west of the Appalachian region, continued over much of the present eastern slope of the Rocky Mountain chain.

We may have hereafter to recognize a *Rocky Mountain region* and a *Western border region*, and others on the north; but at present the geology of these regions is too imperfectly known to render it necessary.

I. AGE OF MOLLUSKS, OR SILURIAN AGE.

This Age is called Silurian, from the region of the ancient Silures in Wales, where the rocks occur. It was first so named by Murchison.

The Age is naturally divided into *Lower* and *Upper* Silurian, each corresponding, in America, to three periods, thus:

1. LOWER SILURIAN.

1. Potsdam, or Primordial Period.

2. Trenton Period: Bala formation and Llandeilo flags of England.

3. Hudson Period: Lower Caradoc, or Upper Llandeilo beds of England.

2. UPPER SILURIAN.

1. Niagara Period: Wenlock beds of England, either in part, or wholly.

2. Salina Period.

3. Lower Helderberg Period: Ludlow beds of England, or all but their upper portion.

The Silurian is also sometimes divided as follows:—

1. PRIMORDIAL SILURIAN, or Potsdam Period. The term Primordial signifies *first* in order, or, in this place, *the period of the first life of the globe.*

2. MIDDLE SILURIAN; corresponding to the remainder of the Lower Silurian.

3. UPPER SILURIAN.—The same as above given.

1. PRIMORDIAL, OR POTSDAM PERIOD.

1. Rocks: kinds and distribution.

The strata of the Primordial or Potsdam period, in America, over the *Interior Continental* basin, are exposed to view at intervals from New York to the Mississippi River; beyond the river, over some parts of the eastern slopes of the Rocky Mountains; and also in Texas. The area on the map of New York and Canada (p. 71) is that numbered 2, lying next to the Azoic. There is reason to believe, from the many points at which the strata come to the surface (as in Michigan, Wisconsin, Iowa, Missouri, Tennessee, Texas, the Upper Missouri region), that they extend over the larger part of the continent outside of the Azoic area represented on the map,

p. 73, though concealed by other less ancient strata over most of the surface.

Through this interior region the lower rocks are mainly a sandstone,—called the *Potsdam sandstone*, from a locality in northern New York. The sandstone beds contain, in many places, ripple-marks (fig. 18, p. 32); mud-cracks (fig. 20); layers showing the wind-drift and ebb-and-flow structure (figs. 17 *f*, *e*,); worm-burrows, and also occasionally the tracks of some of the animals of the period. The upper rocks in New York, and in the same latitudes west, are sandstone, containing some carbonate of lime, and called the *Calciferous* beds; but more to the south in the Mississippi Valley the beds are mainly a magnesian limestone, called the *Lower Magnesian*.

In the *Appalachian region* in Vermont, north in Canada, and in Pennsylvania, etc., the rocks are slates overlying sandstone,—the whole 2000 to 7000 feet or more thick, exceeding many times the thickness to the west. In the *Eastern border* region beds of the period occur at Braintree near Boston, and near the Labrador coast.

In Great Britain the primordial rocks are hard sandstones and slates, called in part the Lingula flags. They are most extensively in view in north and south Wales and in Shropshire. A lower portion of the series, of great thickness, consisting of slates and other rocks, has been named *Cambrian* by Sedgwick.

In Lapland, Norway, Sweden, and Bohemia, Primordial strata have been observed. If the strata of later date could be removed from the continents, we should probably find the primordial beds extensively distributed over all the continents.

2. Life.

These most ancient of fossiliferous rocks contain no remains of *terrestrial* life. The *plants* of the period were all *sea-weeds*. Among *animals*, the sub-kingdoms of *Radiates*,

Mollusks, and *Articulates* were represented by *water-species*, and by these alone. There is no evidence that there were any *Vertebrates*.

The older sandstone abounds in many places in a shell smaller, in general, than a finger-nail, called a *Lingula* (fig. 133). It is the shell of a Mollusk of the tribe of Brachiopods. It stood on a stem, when alive, as represented in fig. 82, p. 55. These shells are so characteristic of the beds in many

Figs. 130–138.

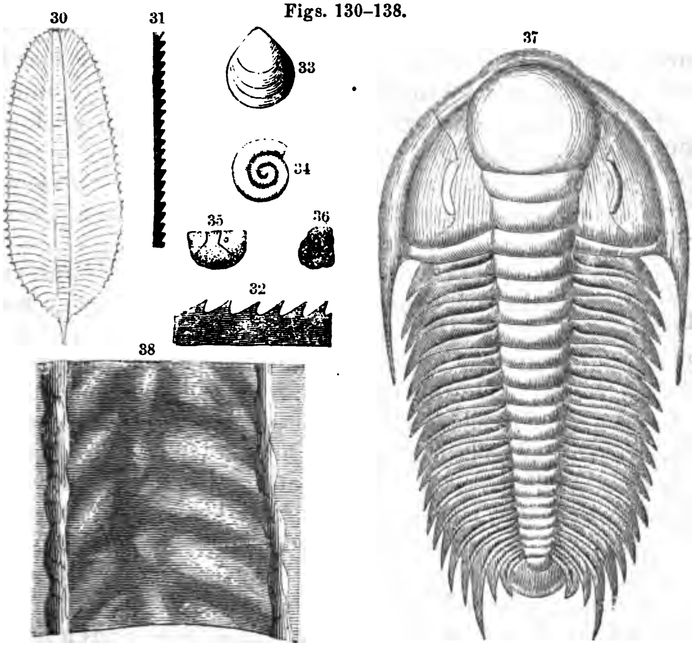


Fig. 130, Phyllograptus Typus; 131, 132, Graptolithus Logani; 133, Lingula prima; 134, Ophileta levata; 135, Leperditia Anna; 136, same, natural size; 137, Paradoxides Harlani (× 1/6); 138, Track of a Trilobite (× 1/6).

regions as to give them the name of *Lingula flags*, or *Lingula sandstone*.

Another tribe very prominent among the earliest of the earth's animals is that of *Trilobites*, of the sub-kingdom of Articulates, and class of Crustaceans.

One of the largest species of them is represented in fig. 137, reduced to one-sixth the natural length. Its total length, when living, must have been 18 inches or more, and hence it was as large as any living Crustacean. The specimen figured was found at Braintree south of Boston. It is seen to have had large eyes situated on the head-shield,—evidence, as Buckland observed, of the clear waters and clear skies of Primordial time. As no legs are ever found in connection with Trilobites, they are supposed to have had only thin membranous or foliaceous plates for swimming. Fig. 138 shows the track of a large animal found by Logan in the Canada beds (and reduced like fig. 137), which may have been made by one of the great Trilobites as it crawled over the sand.

Another group, characterizing especially the later half of the period, is that of *Graptolites*, two specimens of which are shown in figs. 130, 131, and an enlarged view of part of fig. 131 in fig. 132. The species are so named from the Greek *graphō*, *I write*, in allusion to their having commonly a plume-like form. The fossils are very thin, and are supposed to have consisted of the cells of minute Radiate animals, allied to the Hydroid Acalephs (p. 58). A great number of species have been described. They appear to have grown like delicate mossy plants densely over the muddy bottom of the sea.

Among Mollusks, besides Brachiopods, there were also Gasteropods, one of which is shown in fig. 134.

Crustaceans were represented also by a few species a little like shrimps in general form, but having foliaceous legs like the Trilobites, and called *Phyllopods;* also by *Ostracoids*, one species of which is shown, enlarged, in fig. 135, and of natural size in fig. 136. These little Ostracoids, though insignificant in size, are so abundant in some places as nearly to make up the mass of a slate.

The existence of marine *worms* among the earliest animals of the globe, is proved by the great numbers of worm-holes or burrows in the sandstones, now filled with the hard sandstone like that of the rock. They are very similar to the holes made by such worms in the sands of sea-shores at the present time. One species is called *Scolithus linearis.* These worm-holes are common in the European as well as American Primordial sandstones.

There were also *Crinoids* of the sub-kingdom of Radiates (p. 58), for disks from the broken stems of Crinoids are not uncommon. And among Protozoans there were at least *Sponges*, if not also the minute *Rhizopods* and *Polycystines* (p. 59).

Sponges among *Protozoans*,—Graptolites and Crinoids among *Radiates*,—Brachiopods and some representatives of other tribes among *Mollusks*,—Worms and Trilobites, and a few other Crustaceans, among *Articulates*,—and Sea-weeds among *Plants*,—made up the living species; and in this Primordial population, Trilobites took the lead. There is as yet no evidence that the dry Primordial hills bore a moss or lichen, or harbored the meanest insect, or that the oceans contained a single fish.

3. General Observations.

The ripple-marks, mud-cracks, and tracks of animals preserved in this most ancient of Paleozoic rocks are records left by the waves, the sun, and the life of the period, as to the extent and condition of the continent in that early era; and the layers having the wind-drift structure or the ebb-and-flow structure are other evidence of similar import. These markings teach that when the beds were in progress a large part of the continent lay at shallow depths in the sea, so shallow that the waves could ripple its sands;—that over other portions the surface was a sand-flat exposed at low tide; or a sea-beach, the burrowing-place of worms;—or a mud-flat, that could be dried and cracked under the heat of the sun, or in a drying atmosphere; or a field of drift heaps of sands, beyond the reach of the tides, which the winds, now gentle in movement, and now blowing in gales, had gradually built up.

With such evidences of shallow water or emerged sand in a formation extending widely over the continent, it is a safe conclusion that the North American continent was at the time in actual existence, and probably not far from its present extent; and, although partly below the sea-level, it was generally at shallow depths. The same may prove to have been true of the other continents. There is, in fact, evidence of other kinds which, taken in connection with the above, leaves little doubt that the existing places of the deep ocean and of the continents were determined even in the first formation of the earth's crust in the early Azoic, and that, in all the movements that have since occurred, the oceans and continents have never changed places.

This preservation of markings, seemingly so perishable, on the early shifting sands, is a very instructive fact. They illustrate part of the means by which the earth has, through time, been recording its own history. The track of a Trilobite or of a wavelet is a mould in sand or earth, into which other sands are cast both to copy and preserve it; for if the waves or currents that succeed are light, they simply spread new sands over the indented surface, without obliterating the mould; and so the addition of successive layers only buries the markings more deeply and thus protects them against destruction. When, finally, consolidation takes place, the track or ripple-mark is made as enduring as the rock itself.

After the formation in North America of the great Primordial sandstone, there was a change in the condition of the surface, especially over the interior of the continent. For limestone strata began then to form where sandstones were in progress before. This change was probably some increase in the depth and clearness of the interior of the continental sea. Along the borders of this sea—that is, in New York and along the Appalachian region from Quebec into Virginia—the rock was still a sandstone or shale, though often more or less calcareous in its composition.

The limestone of the interior region is remarkably free from fossils; and if, as is probable, it was of organic origin, it follows either that the fossils were all ground to powder to make the rock, or else they were too minute to need grinding,—like the Rhizopods figured on page 59, which seldom exceed the finest grains of sand in size. Now, since such Rhizopods made the strata of chalk at a later age, and since also they constitute at the present time the bed of the ocean over immense areas in both deep and shallow waters, and inasmuch as their existence in the Lower Silurian era has been proved by finding fossils of them (though not in the rock here under consideration), it is certainly possible that the magnesian limestones of the period may have been formed out of the remains of Rhizopods.

Whether the reasoning here used be regarded as satisfactory or not, the above will serve to illustrate the methods of searching into the geography of the ancient world that are within the reach of the geologist. And when the facts are all fully known, there is little reason to doubt that the results arrived at will be in the main right.

2. TRENTON AND HUDSON PERIODS.

The Middle Silurian includes the *Trenton* and *Hudson* periods of America, and those of the *Bala limestone* and *Llandeilo flags* of Great Britain.

Rocks: kinds and distribution.

In the Primordial period of America, there was, first, the spreading out of a great sandstone over the submerged portions of the continent; afterwards, the formation of a limestone about the middle of the *Interior Continental* basin, while sandstones but little calcareous were forming along the northern United States and over the *Appalachian* region.

In the next period, called the Trenton, limestones were in progress over the Appalachian region, as well as a very large part of the Interior Continental basin,—northeastern, northern, and southern. It was the most universal of all limestone formations. It is numbered 3 on the map, p. 71.

The rock differs from the Lower Magnesian limestone in being full of fossils,—shells, crinoidal remains, corals, etc.; and often the fossil shells and corals are so crowded together that no spot as large as the end of the finger can be found without one or more of them. In fact, if the portions which seem to be without them are sliced very thin and examined under a microscope, they are found to be made up of fragments of fossils.

The thickness of these rocks in some portions of the *Appalachian* region is 6000 to 8000 feet, or more than ten times the thickness in the larger part of the *Interior Continental* region.

The name *Trenton* is derived from Trenton Falls, north of Utica, New York, where the Trenton limestone is exposed in high bluffs along the banks of the stream. The "Chazy," "Birdseye," and "Black River" limestones are the lower strata, in succession, of the Trenton Period, the Chazy being the oldest.

In the Green Mountains these limestones are now in the condition of white statuary or building marble; for they are the marbles of the Stockbridge and other quarries in

Berkshire, Massachusetts, and of those of Vermont. They have been altered or metamorphosed, in this part of the Appalachian region, into a crystalline rock, or, in other words, they are *metamorphic* limestones (see p. 21). In the process of change they have lost all their fossils, excepting a rare example, as at Sudbury, Vermont. Other associated rocks in the same region are also metamorphic, or more or less crystalline.

Before the close of the Lower Silurian—that is, in the Hudson period—the area of limestone-making had again contracted. Over the *Appalachian* region in Pennsylvania, and in the northern portion of the *Interior Continental* region, —that is, through New York State and the same latitudes to the westward,—the rocks are shales and shaly sandstones; while in Ohio and some other States beyond they consist of shales and limestones, or shaly limestones. The *Utica shale* and *Lorraine shale* of central New York are of this period (see No. 4, on the map, p. 71).

The rocks of the Middle Silurian, in Great Britain, are shales and shaly sandstones, with but little limestone. The Llandeilo flags are shaly sandstones; and, together with the associated shales, they have a thickness of many thousand feet. Above them there are the Caradoc sandstone of Shropshire and the Bala formation—the latter including some limestone in Wales. In Scandinavia there are limestone formations, overlaid by slates and flags; in Russia and the Baltic provinces—part of the *Interior Continental* portion of the Eastern Continent—the rocks are mainly limestones.

2. Life.

The life of the Middle Silurian, like that of the Primordial period, was, as far as evidence has been collected from the American or foreign rocks, wholly marine: no trace of a terrestrial or fresh-water species of plant or animal has been found.

The plants were *sea-weeds* alone.

All the sub-kingdoms of animals were represented, *with the exception of the Vertebrates.* Among *Radiates* there were Corals and Crinoids; among *Mollusks*, representatives of all the several orders; among *Articulates*, the water-divisions, Worms and Crustaceans.

1. *Radiates.*—Fig. 139 represents one of the Corals. Its shape is that of a curved cone, a little like a short horn, the small end being the lower. At top, when perfect, there is a cavity divided off by plates radiating from the centre. Such corals are called *Cyathophylloid* corals, from the Greek *kuathos*, *cup*, and *phullon*, *leaf*, alluding to the cup full of radiating leaves or plates. When living, the coral occupied the interior of an animal similar to that represented in fig. 94 or 95.

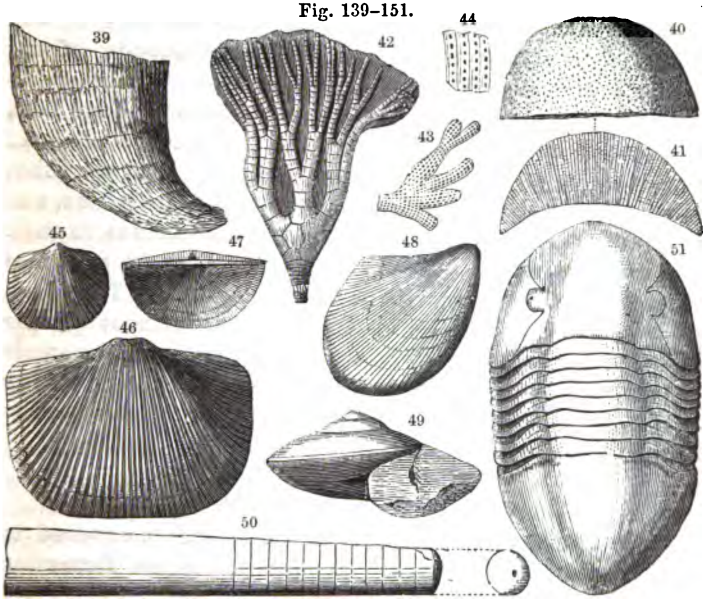
Another kind of coral, of a hemispherical form, and made up of very fine columns, is represented in figs. 140, 141, the latter showing the interior appearance. It is called *Chætetes Lycoperdon.* Another, of coarser columns,—each nearly a sixth of an inch in diameter,—is called the *Columnaria alveolata.* In a transverse section the columns are divided off by horizontal partitions. Masses of this coral have been found which weigh each between two and three thousand pounds.

Fig. 142 shows the form of one of the Crinoids, though the stem on which it stood is mostly wanting, and the arms are not entire. The mouth was in the centre above, and the animal was like a star-fish with branching arms, turned bottom-upward, and standing on a jointed stem. There were also true star-fishes in the seas.

2. *Mollusks.*—Among *Mollusks*, Bryozoans were very common: the fossils are small cellular corals: one is shown in fig. 143, and a portion, enlarged, in fig. 144. Brachiopods were still more characteristic of the period, and occur in vast numbers. Fig. 145 is *O. testudinaria;* fig. 146, *O. occidentalis;* fig. 147, *Leptæna sericea.* There were also some

Conchifers, as fig. 148, *Avicula? Trentonensis;* and some Gasteropods, as fig. 149, *Pleurotomaria lenticularis.* Shells

Fig. 139–151.



RADIATES.—Fig. 139, Petraia Corniculum; 140, 141, Chætetes Lycoperdon; 142, Lecanocrinus elegans.—MOLLUSKS: Figs. 143, 144, Ptilodictya fenestrata; 145, Orthis testudinaria; 146, Orthis occidentalis; 147, Leptæna sericea; 148, Avicula (?) Trentonensis; 149, Pleurotomaria lenticularis; 150, Orthoceras junceum.—ARTICULATES: Fig. 151, Asaphus (Isotelus) gigas.

of Cephalopods were especially common under the form of a straight or curved horn with transverse partitions. Fig. 150, *Orthoceras junceum*, represents a small species. One kind had a shell 12 or 15 feet long and nearly a foot in diameter. The word *Orthoceras* is from the Greek *orthos*, *straight*, and *keras*, *horn*.

There were some species also of the genus Nautilus.

3. *Articulates.*—Fig. 151 represents one of the large Trilobites of the Trenton rocks, the *Asaphus gigas*,—a species

sometimes found a foot long. Another Trilobite is the *Calymene Blumenbachii*, of Europe, represented in fig. 73, p. 54, very similar to the *C. senaria* of the American rocks.

While Trilobites appear to have been the largest and highest life of the Primordial seas, Cephalopods, of the Orthoceras family, far exceeded Trilobites in both respects in the Trenton period. The larger kinds must have been powerful animals to have borne and wielded a shell 12 or 15 feet long. Although clumsy compared with the fishes of a later age, they emulated the largest of fishes in size, and no doubt also in their voracious habits. Crustaceans, in their highest divisions, as the Crabs, may perhaps be regarded by some as of superior rank to Cephalopods. But Trilobites, of the inferior division of Crustaceans, without proper legs, living a sluggish life in slow movement over the sands or through the shallow waters, or skulking in holes, or attached like limpets to the rocks, were far inferior species to the Cephalopods.

3. General Observations.

1. **Geography.**—The wide continental region covered in the Trenton period by the Trenton limestone formation stretching over the *Appalachian* region on the east, and widely through the *Interior* basin, must have been throughout a clear sea, densely populated over its bottom with Brachiopods, Corals, Crinoids, Trilobites, and the other life of the era. It may, however, have been a *shallow* sea; for the corals and beautiful shells of coral reefs live mostly within 100 feet of the surface.

During the next, or Hudson period, the same seas, especially on the north, became less free from sediment, through some change of level or of coast-barriers, and consequently much of the former life disappeared, and other kinds supplied their places, adapted to impure waters or to muddy bottoms.

2. Disturbances during the Lower Silurian, and at its Close.—(1.) *Igneous ejections in the Lake Superior district.*—Before the close of the Primordial period there were extensive igneous ejections through fractures of the earth's crust in the vicinity of Lake Superior, about Keweenaw Point and elsewhere, and probably to some extent also over the bottom or area of the lake itself, for this is indicated by the dikes and columnar trap of Isle Royale, an island in the lake. These rocks, which were melted when ejected, now stand, in many places, in bold bluffs and ridges; and mixtures of scoria and sand make up some of the conglomerate beds of the region. The sandstones, penetrated by the dikes of trap, and made partly before and partly after the ejection, have a thickness in some places of six or eight thousand feet. There appears to have been a sinking of the region equal to the thickness of the beds, in addition to the igneous ejections. The great veins of native copper of the Lake Superior region are part of the results of this period of disturbance.

(2.) *Emergence of the region of the Green Mountains.*—The changes from deep to shallow seas, or partly emerged flats, during the Silurian era, are evidence that changes of level, by gentle movements or oscillations in the earth's crust, were going on throughout it. But after the Lower Silurian had closed, or toward its close, there appear to have been greater and more permanent changes. The valley of Lake Champlain and the Hudson, as shown by Logan, probably dates from this time. The Green Mountains, though not raised to their full height, then became stable dry land, like the Azoic regions on the map, p. 73. That they were not dry land before, is shown by the Trenton limestones in their structure, for these are of marine origin; and that their western side and summit were above the water from and after this time, is indicated by the fact that the formations of the Middle Silurian are the latest that were there formed.

Upper Silurian and Devonian rocks exist over New England on the east, and over much of the State of New York on the west (see map, p. 71), but not about the top or western side of this range.

The Green Mountains appear, therefore, to have been the portion of the great Appalachian chain which first became stable land.

The vast thickness of the several Lower Silurian formations along the course of the Appalachian chain, as mentioned on pages 80, 86, and the contrast in this respect with the Interior Continental region, are indications that preparation was making throughout the Appalachian region which were to result ultimately in mountains: the raising of part of the Green Mountains above the sea-level, though it may have been but to a very small height, was the commencement of the elevation of the Appalachian chain.

3. Life.—(1.) *Progress.*—There is no evidence that the system of life in its progress during the Primordial and Middle Silurian had so far advanced as to include a terrestrial species, or the lowest of Vertebrates. Trilobites held the first position in the former of these eras, Orthocerata and other Cephalopods in the latter.

It was the *Age of Mollusks;* and while Cephalopods took the lead in the life of the world, all the other orders of Mollusks had their representatives. No other sub-kingdom was as well displayed in its several grand divisions, not even that of the Radiates. Among Articulates, there were neither Myriapods, Spiders, nor Insects; for these are essentially *terrestrial* animals, and the first species of them thus far discovered are of the Devonian age.

(2.) *Exterminations and Creations.*—Among the *genera* of the Lower Silurian, only five have living species. These are *Lingula*, *Discina*, *Rhynchonella*, and *Crania* among Brachiopods, and *Nautilus* among Cephalopods. These genera of long lineage thus reach through all time from the beginning of the systems of life. All other genera disappear,—some at the close of the Primordial, others at that of the Trenton or Hudson period, or even at the termination of subordinate epochs within these periods.

The extermination of species took place at intervals through the periods, as well as at their close; though the latter were most universal. With the changes from one stratum to another there were disappearances of some species, and with the changes from one formation to another, still larger proportions became extinct. No Primordial species are known to occur in the Trenton period; very few of the species of the earlier epoch of the Trenton survive into the next epoch; and very many of those of the Trenton did not exist in the Hudson period. Thus life and death were in progress together, species being removed, and other species being created, as time moved on.

In the first chapter of Genesis we read that on the *fifth* day *the waters brought forth abundantly the moving creature that hath life;* and the rocks declare most decisively that the waters were filled with life when the Silurian age opened,—although but the earlier species of the life of that fifth day. The eyes of the Trilobites have been referred to as evidence of sunshine and clear skies in that early era. The existence of so much animal life is itself as good proof of the fact; for without the sun the systems of life could not have had even the display they presented in the Primordial period. It is clear, therefore, that although the first vegetation may have existed in Azoic time, while the seas were unduly warm and while, therefore, the earth was densely shrouded in clouds, as the Zoic ages began the clouds were already broken, and the earth had completed its garniture of sky and "greater and lesser lights."

3. UPPER SILURIAN ERA.

1. Subdivisions.

The Upper Silurian in North America includes three periods: the NIAGARA, the SALINA, and the LOWER HELDERBERG. The name of the *first* is from the Niagara River, along which the rocks are displayed; that of the *second*, from Salina in central New York, the beds being the salt-bearing rocks of that part of the State; that of the *third*, from the Helderberg Mountains, south of Albany, where the lower rocks are of this period.

2. Rocks: kinds and distribution.

The rocks of the *Niagara* period are—1, a conglomerate and grit-rock called the *Oneida conglomerate*, which extends from central New York southward along the Appalachian region, having a thickness of 700 feet in some parts of Pennsylvania; 2, shaly sandstones of the *Medina group*, which spread westward from central New York through Michigan, and also southward along the Appalachian region, being 1500 feet thick in Pennsylvania; 3, hard sandstones, or flags and shales of the *Clinton group*, having nearly the same distribution as the Medina formation, though a little more widely spread in the west, and about 2000 feet thick in Pennsylvania; 4, the *Niagara group*, occurring in western New York, and extending widely over both the Appalachian and Interior Continental regions; it consists of shales below and thick limestone above at Niagara, mainly of limestone in the *Interior region*, and of clayey sandstone or shales in the Appalachian region, where it has a thickness of 1500 feet or more. The Niagara is one of the great limestone formations of the continent, existing also in the Arctic regions.

Ripple-marks and mud-cracks are very common in the

Medina formation. The example of rill-marks figured on page 32 is from its strata in western New York.

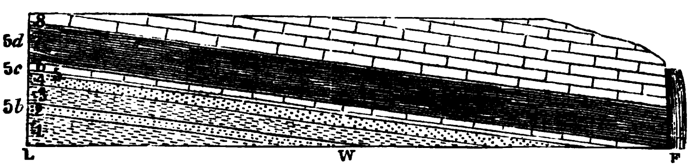
The *Salina* rocks are fragile clayey sandstones, marlites, and shales, usually reddish in color, and including a little limestone. They occur in New York and sparingly to the westward, being thickest (700 to 1000 feet thick) in Onondaga county, N.Y.

The salt of Salina and Syracuse, in central New York, is obtained from wells of salt water 150 to 310 feet deep, which are borings into these saliferous rocks. 35 to 45 gallons of the water afford a bushel of salt, while of sea-water it takes 350 gallons for the same amount. No salt is found in solid masses. Gypsum is common in some of the beds. A limestone called the Guelph formation overlies the Niagara beds at Guelph and in some other parts of western Canada.

The *Lower Helderberg* group consists mainly of limestones, and is the second limestone formation of the Upper Silurian. But the rock is generally impure or earthy, and the formation is mostly confined to the State of New York and to the Appalachian region on the south.

The section, fig. 152, represents the rocks on the Niagara River at and below the Falls. The falls are at F; the whirlpool, 3 miles below, at W; and the Lewiston Heights, which front Lake Ontario, at L. Nos. 1, 2, 3, 4 are different sand-

Fig. 152.



Section along the Niagara, from the Falls to Lewiston Heights.

stone strata belonging to the Medina group; 5, shale, and 6, limestone, to the Clinton group; 7, shale, and 8, limestone, to the Niagara group. (Hall.) The next section (fig. 153), from the region south of the eastern part of Lake Ontario, consists as follows:—5 *b*, Medina group, 5 *c*, Clinton

Fig. 153.

Section of the Salina and underlying strata, from north to south, south of Lake Ontario.

group, 5 *d*, Niagara group (shale and limestone), 6, Salina beds. (Hall.)

In Great Britain, the Upper Silurian rocks are first sand-stones and shales, called, when occurring in South Wales, *Llandovery beds*, and corresponding to the Medina and Clinton groups; above these, the *Wenlock* limestone group, consisting of limestone and some shale (and including in the upper portion the *Dudley* limestone). These rocks occur as surface-rocks near the borders of Wales and England. Next comes the *Ludlow group*, of the age of the Lower Helderberg, and perhaps also of the first part of the American Devonian.

In Scandinavia, the Gothland limestone is the equivalent of the Niagara.

3. Life.

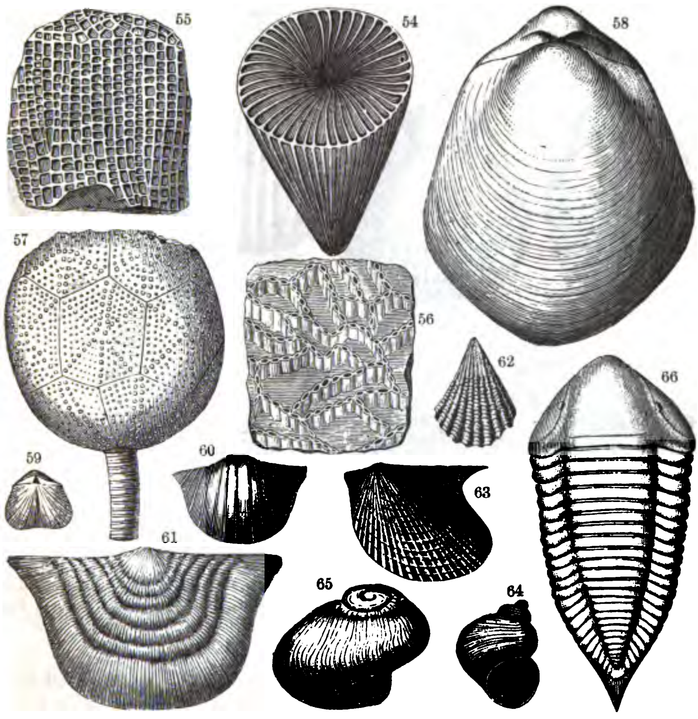
The limestone strata and most of the other beds of the Niagara group are full of fossils; so also are the rocks of the Lower Helderberg period, and the Wenlock and Ludlow formations of Great Britain. The Salina formation is almost wholly destitute of them.

The life of the era was the same in general features as that of the later half of the Lower Silurian. It was wholly marine.

The only plants were *Algæ*, or sea-weeds.

In the Animal Kingdom the sub-kingdom of *Radiates* was represented by Corals and Crinoids; that of *Mollusks*, by species of all the grand divisions, among which the Brachiopod and Orthoceras tribes were the most prominent, and especially the Brachiopod, whose shells far outnumber those

Figs. 154–166.

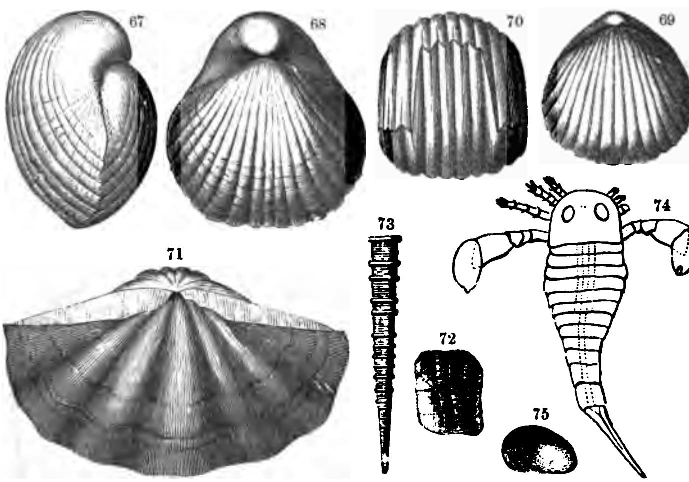


RADIATES: Fig. 154, Zaphrentis bilateralis, Clinton group; 155, Favosites Niagarensis, Niagara group; 156, Halysites catenulatus, id.; 157, Caryocrinus ornatus, id.—MOLLUSKS: Fig. 158, Pentamerus oblongus, Clinton gr.; 159, Orthis biloba (× 2), Niagara gr. and Dudley limestone; 160, Leptæna transversalis, id.; 161, Spirifer Niagarensis, id.; 162, Rhynchonella cuneata, U. S. and Great Britain; 163, Avicula emacerata, Niag. gr.; 164, Cyclonema cancellata, Clinton gr.; 165, Platyceras angulatum, Niag. gr.—ARTICULATES: Fig. 166, Homalonotus delphinocephalus.

of all other Mollusks; that of *Articulates*, by Worms, Ostracoids, and Trilobites; and before the close of the era, by the new form of Crustaceans represented in fig. 174.

1. *Radiates.*—Fig. 154 is a polyp-coral of the *Cyathophylloid* tribe, showing the radiating plates of the interior; fig. 155, a species of *Favosites*, a genus in which the corals have a columnar structure, and horizontal partitions subdivide

Figs. 167–175.



MOLLUSKS: Figs. 167, 168, Pentamerus galeatus; 169, 170, Rhynchonella ventricosa; 171, Spirifer macropleurus; 172, Tentaculites ornatus; 173, id. enlarged.—ARTICULATES: Fig. 174, Eurypterus remipes, a small specimen; 175, Leperditia alta. Species all from the Lower Helderberg group.

the cells within; fig. 156, *Halysites catenulatus*, called *chain-coral;* fig. 157, a Crinoid, *Caryocrinus ornatus*, the arms at the summit broken off; fig. 89, p. 57, another Crinoid of the family of *Cystideans*, from the Niagara group; fig. 87, p. 57, a star-fish, also from the Niagara group.

2. *Mollusks.*—Figs. 158 to 162, different Brachiopods of the Niagara period; figs. 167 to 171, other species characteristic of the Lower Helderberg period; figs. 164, 165, Gasteropods of the Niagara period; fig. 172, small slender tubular cones, called *Tentaculites*, almost making up the

mass of some layers in the Lower Helderberg; the form of one of them, enlarged, is shown in fig. 173.

3. *Articulates.*—Fig. 166, a reduced figure of a common Trilobite of the Niagara group, a species of *Homalonotus*, often having a length of 8 or 10 inches; fig. 174, *Eurypterus remipes*, of a new family of Crustaceans, commencing in the Lower Helderberg; it is sometimes nearly a foot long; species of the same family occur in Great Britain in the Ludlow beds, and one of them is supposed, from the fragments found, to have been 6 or 8 feet long, far surpassing any Crustacean now living; fig. 175, an *Ostracoid* Crustacean, the *Leperditia alta*, of unusually large size for the family, modern Ostracoids seldom exceeding a twelfth of an inch in length.

In the Upper Ludlow beds of Great Britain a few remains of *land-plants* and of *fishes* have been found. But, from the similarity of many fossils of the upper part of the Ludlow beds to those of the Upper Helderberg, it is probable that these Upper Ludlow beds, if referred to the American system of subdivisions, would rank as Devonian.

4. General Observations.

1. **Geography.**—On the map, p. 69, the areas over which the Silurian formations are surface-rocks are distinguished by being *horizontally* lined. It is observed that they spread southward from the northern Azoic.

South of the Silurian area commences the Devonian, which is *vertically* lined; and the limit between them shows approximately the course of the sea-shore at the close of the Silurian age. It is seen that more than half of New York, and nearly all of Canada and Wisconsin, had by that time become part of the dry land; but a broad bay covered the Michigan region to the northern point of Lake Michigan, for here Devonian rocks, and to some extent Carboniferous, were afterwards formed. The Azoic dry land, the back-bone of the continent, had also received additions in a similar manner on its eastern and western sides, through British America.*

But, with all the increase, the amount of dry land in North America was still small. Europe is proved by similar evidence to have had much undry land. The surface of the earth was a surface of great waters, with the continents only in embryo,—one large area and some islands representing that of North America, and an archipelago that of Europe. The emerged land, moreover, was most extensive in the higher latitudes. The rivers of a world so small in its lands must also have been small. The lands, too, according to present evidence, were barren, except perhaps during the closing part of the age.

The succession of Upper Silurian formations is as follows:—(1) The coarse grit called Oneida conglomerate, occurring of great thickness along the Appalachian region, and reaching north to central New York; (2) the Medina sandstone, also very thick along the Appalachian region, and extending northward to central New York, and, besides, spreading westward beyond the limits of that State; (3) the Clinton group of flags and shales, having the same Appalachian extension and great thickness, but spreading on the north much farther westward, even to the Mississippi; (4) the Niagara group, covering the Appalachian region deeply with sandstone and shales, and New York with shales and limestones, and spreading as a great limestone formation through the larger part of the Interior region; then (5) the limited Salina salt-bearing marlites of New York,

* On the map referred to, page 69, lines of the Silurian and Devonian are seen to extend from the Hudson River southwestward along the Appalachian region. But the outcrop of the Silurian, here represented, is not evidence that there was a strip of dry land along this region from the close of the Silurian era, because there is proof that these Appalachian outcrops are a consequence of the uplift of the Appalachian Mountains, an event of much later date. (p. 156.)

and the Appalachian region southwest, with some cotemporaneous limestones in Canada; then (6) another limestone, but impure and mostly confined to New York State and the Appalachian region. These facts teach that geographical changes took place from time to time, in the course of the era, corresponding to these several changes in the formations. The clear continental seas of the Trenton period were succeeded by conditions fitted to produce the several arenaceous and argillaceous formations, of varying limits, which followed; and then they were again in existence at the epoch of the Niagara group, when corals, crinoids, and shells covered the bottom of the continental sea and made the Niagara limestone formations. But the pure continental seas in the Niagara epoch were less extended than those of the Trenton; for the Appalachian region, instead of being part of the pure sea and making limestones, was receiving great depositions of sand and clay, as if it were at the time a broad reef, or bank, bordering the Atlantic Ocean.

The Niagara epoch of limestone-making was followed by the Salina or Saliferous period. As the beds are (1) clays and clayey sands, (2) are almost wholly without fossils, and (3) afford salt, it may be inferred that central New York was at the time a great salt marsh, mostly shut off from the sea. Over such an area the waters would at times have become too salt to support life, owing to partial evaporation under the hot sun, and too fresh at other times, from the rains. Moreover, muddy deposits would have been formed; for they are now common in salt marshes wherever there is, as there was then, no covering of vegetation, and the salt waters would naturally have yielded salt on evaporation in the drier seasons. Through an occasional ingress of the sea, the salt waters might have been re-supplied for further evaporation.

There is direct testimony as to the condition of the land and shallowness of the waters in the regions where many of the rocks were in progress; for ripple-marks and mud-cracks are common in some layers, and are positive evidence that the sands and earth that are now the solid rock were then the loose sands of beaches, sand-flats, or sea-bottoms, or the mud of a salt marsh. Such little markings, therefore, remove all doubt as to the condition of central New York in the Salina period.

Similar markings indicate, also, the precise condition of the region of the Medina sandstone, showing that there were sand-flats, sea-beaches, and muddy bottoms open to the inflowing sea. Where the *rill-marks* were made (fig. 19, p. 32) the sands of the spot were those of a gently sloping flat or beach; the waters swept lightly over the sands, dropping here and there a stray shell (as the *Lingula cuneata*) or a pebble, which became partly buried; and then, as they retreated, they made a tiny plunge over the little obstacle and furrowed out the loose sand below it. The firmness of the sand, lightness of the shells, and smallness of the furrows are proof that the movements were light.

The great thickness of the several formations of the Upper Silurian along the Appalachian region leads to many interesting conclusions. It has been stated (p. 92) that the Appalachian formations of the earlier Silurian were equally remarkable for their great thickness. The Appalachian region, from the Primordial era onward, was, hence, in strong contrast with the Interior Continental region, where the series of cotemporaneous beds are hardly *one-tenth* as thick. Taking this into connection with another fact, that very many of the strata among the thousands of feet of Silurian formations in the Appalachian region contain those evidences of shallow water and mud-flat or sand-flat origin above explained, there is full proof that in the Silurian era the region was for the most part, as already suggested, a vast sand-reef, ever increasing by new accumulations under the action of the waves and currents of the ocean. It was much of the time a great barrier-reef lying between the open ocean and the Interior Continental sea; and under its lee, this inner sea, opening southward through the area of the Mexican Gulf, was often in the best condition for the growth of the shells, corals, and crinoids of which the great limestones were made.

While the Appalachian region was alike in its general condition through the earlier and later Silurian, the limits of the formations in progress during these two eras were somewhat different. The Green Mountain portions of the region took no part in the new depositions during the Upper Silurian era. The fact stated on page 91, that it had become part of the comparatively stable and emerged portion of the continent, is thus proved; for if it had been under water, some Upper Silurian beds would have been formed about its western or central portions. The part of the Appalachian region which participated, during the Upper Silurian era, in the great changes connected with the formation of rocks, extended northward from Pennsylvania into New York, and not along the Green Mountains; the rocks in the State of New York have great thickness for some distance beyond the Pennsylvania border, but thin out about the centre.

2. **Life.**—In the Upper Silurian the highest species of the seas and of the world continued to be Mollusks, of the order of Cephalopods. At the same time, Trilobites were the first of Articulates, and sea-weeds the highest of plants.* Corals and Crinoids were the only species of life that had the semblance of flowers. These flower-animals foreshadowed the flowers of the vegetable kingdom for ages before any of the latter existed.

There had been, however, considerable progress in the unfolding of the system of life, through the creation of new species and the introduction of new genera and families,

* The only exceptions to this remark yet known are alluded to on page 99.

cotemporaneously with the extinction of the older forms. In the Lower Silurian era at least 1000 species of animals became extinct in America, and 600 in Great Britain; and in the Upper Silurian 800, or more, in America. The kind of progress which was exhibited is explained on a future page.

II. AGE OF FISHES, OR DEVONIAN AGE.

1. Subdivision.

The Devonian Age may be divided into two eras,—an *earlier* and a *later*,—or that of the *lower* and that of the *upper* formations. The *earlier* includes the periods ORISKANY and CORNIFEROUS; the *later*, the HAMILTON, CHEMUNG, and CATSKILL. The Oriskany period might with almost equal propriety be annexed to the Upper Silurian. The distinction of the Catskill from the Chemung is questioned.

2. Rocks: kinds and distribution.

1. *Earlier and Later eras.*—The earlier Devonian is remarkable for a great limestone formation, which spread from New York over a large part of the Interior region, and nearly equalled the Trenton in extent; while the later has almost no limestones, the rocks being sandstones and shales with some conglomerates.

2. *Oriskany Period.*—The first of the formations, the *Oriskany sandstone*, is a rough-looking, earthy rock. It extends along the Appalachian region, and northward in New York to the vicinity of Oriskany. A rock of the same age occurs also in the Eastern border region in Maine and Nova Scotia. To this succeeds the—

3. *Corniferous Period.*—Its lowest rocks are fragmental beds, called the *Cauda-Galli grit* and the *Schoharie grit*, having their distribution along the Appalachian region,

commencing in central and eastern New York and extending southwestward.

Next follows the great *Corniferous limestone*, the lower part of which is sometimes called the *Onondaga limestone*, and the whole often the *Upper Helderberg group*. It stretches from eastern New York westward to the States beyond the Mississippi.

The name *Corniferous* (derived from the Latin *cornu*, *horn*) was given it by Eaton, from its frequently containing a kind of flint called *hornstone*.

This hornstone differs from true flint in being less tough, or more splintery in fracture, though it is like it in hardness and in consisting wholly of silica.

The limestone is literally an ancient coral reef. It contains corals in vast numbers and of great variety; and in some places, as near Louisville, Kentucky, at the Falls on the Ohio, the resemblance to a modern reef is perfect. Some of the coral masses at that place are 6 or 8 feet in diameter; and single polyps of the Cyathophylloid corals had in some species a diameter of 2 and 3 inches, and in one, of 6 or 7 inches.

The same reef-rock occurs near Lake Memphremagog on the borders of Vermont and Canada; but the corals have there been partly obliterated by metamorphism. The limestone occurs among metamorphic schists, a talcose schist overlying it, according to Hitchcock. The crystalline rocks extending south through Vermont into Massachusetts, and the granites and gneiss of the White Mountains, are supposed to be altered Devonian sandstones and shales.

4. *Hamilton Period.*—The Hamilton formation consists of sandstones and shales, with a few thin layers of limestone. It consists of three parts, corresponding to three epochs: the lower part is called the *Marcellus shale;* the middle, the *Hamilton beds;* and the upper, the *Genesee shale.* It has its greatest thickness along the Appalachians. From New

York it spreads westward, and, in the form of what is called *black slate*, more properly a *black shale* (supposed to be of the epoch of the Marcellus shale), it is widely known through the Interior Continental region.

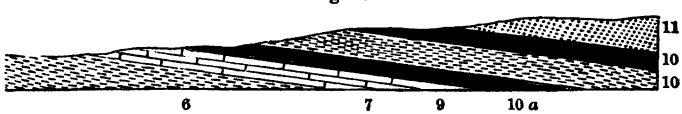
The Hamilton beds afford an excellent flagging-stone in central New York and on the Hudson River, which is extensively quarried and exported to other States.

5. *Chemung Period.*—The Chemung beds are mainly sandstones, or shaly sandstones, with some conglomerate. They spread over a large part of southern New York, having great thickness in the Catskill Mountains.

The formation along the Appalachians is 5000 feet thick. It thins out to the west of New York, in Ohio, and Michigan.

In the following section, taken on a north-and-south line south of Lake Ontario, No. 6 represents the beds of the

Fig. 176.



Section of Devonian formations south of Lake Ontario.

Salina period; overlaid by 7, the Lower Helderberg limestone; 9, the Corniferous, or Upper Helderberg limestone; 10, *a*, *b*, *c*, the Hamilton beds; and 11, the Chemung group.

6. *Catskill Period.*—The Catskill rocks of New York have been considered as pertaining to a *Catskill* period; but recent observations have shown that they are part of the Chemung formation. It is not yet known that the same is true of the sandstones and shales of Pennsylvania, referred to the Catskill period, which are stated to have a thickness of 6000 feet.

In Great Britain, the Devonian rocks have been called the *Old Red Sandstone*, the prevailing rock in Wales and Scotland being a red sandstone. This sandstone formation, however, includes marls of red and other colors, and some limestone. The distribution in Great Britain is shown on the map, p. 120. In Germany, in the Rhenish provinces, there is a coral limestone very similar to that of North America.

3. Life.

1. *General characteristics.*

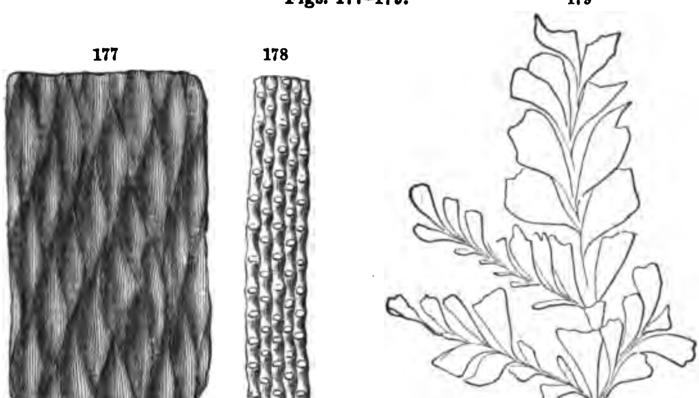
The Devonian of North America, as far as now known, is the era of the first of *terrestrial plants*, the first of *Insects* or *terrestrial Articulates*, and the first, also, of *Vertebrates*. These early *Vertebrates* were *Fishes*,—the species that belong to the water.

2. *Plants.*

Figs. 177–179 represent portions of some of the plants. Fig. 179 is a fragment of a *fern*, and figs. 177, 178, portions

Figs. 177–179.

177 178 179



PLANTS.—Fig. 177, Lepidodendron primævum, from the Hamilton group; 178, Sigillaria, ibid.; 179, Noeggerathia Halliana, from the Chemung group.

of the trees, of the age. The scars or prominences over the surface are the bases of the fallen leaves: a dried branch of a Norway spruce, stripped of its leaves, looks closely like fig. 178. By referring to page 60, it will there be seen that among the Cryptogams there is one order, the highest, or that of *Acrogens*, in which the plants have upward growth like ordinary trees, and the tissues are partly vascular: it is the one containing the *Ferns*, *Lycopodia*, and *Equiseta*. The most ancient of land plants belong, to a great extent, to this order,—the *highest of Cryptogams*. Another portion are related to the lowest order of *flower-bearing* plants, or *Phenogams*, called *Gymnosperms* (see p. 61).

The groups represented under these divisions are the following:—

I. Flowerless Plants, or Cryptogams, *Order of* Acrogens.

1. *Fern tribe.*—The species have a general resemblance to the ferns or brakes of the present time.

2. *Lycopodium tribe*, or that of the *Ground-pine.*—The existing plants of this tribe are slender species, seldom over 4 or 5 feet high: some of the ancient were of the size of forest-trees. These ancient species belong mostly to the *Lepidodendron* family, in which the scars are contiguous and are arranged in quincunx order,—that is, alternate in adjoining rows,—as shown in fig. 177. The Ground-pine of our woods, although flowerless like the fern, has leaves very similar to those of the spruce or cedar (Conifers); and this type of plants is intermediate in some respects between the Acrogens and Gymnosperms (Conifers).

3. *Equisetum tribe.*—The Equiseta of modern wet woods are slender, hollow, jointed rushes, called sometimes *scouring-rushes*. They often have a circle of slender leaf-like appendages at each joint.

The *Calamites*, or *tree-rushes*, are peculiar to the ancient world, none having existed since the Mesozoic. They had jointed striated stems like the Equiseta, and otherwise resembled them. But they were often a score of feet or more in height, and sometimes 6 inches in diameter. Some of them had hollow stems like the Equiseta; others had the interior of the stems woody, and these were intermediate in some respects between the Equiseta and the Gymnosperms. Fig. 225, under the Carboniferous age, represents a portion of one of these plants.

II. FLOWERING PLANTS, OR PHENOGAMS, *of the Order of* GYMNOSPERMS.

1. *Conifers.*—The species are related to the common pines and spruces, or more nearly to the Araucarian pines of Australia and Soúth America. The fossils are merely portions of the trunk or branches. It has been suggested by Mr. Lesquereux that all the specimens belong to the following tribe:—

2. *Sigillarids.*—The *Sigillariæ* were trees of moderate height, with stout, sparingly-branched trunks, bearing long linear leaves much like those of the Lepidodendra. The scars on the exterior are mostly in parallel vertical lines, as in fig. 178 and fig. 222, p. 127, and not in quincunx order, like those of the Lepidodendra.

The earliest fossil land-plants thus far found in the United States occur in the Hamilton formation. Whether they occur lower than this, or in earlier Devonian, in Canada and New Brunswick, is not certain.

Conifers, Ferns, and Lepidodendra have also been reported from some of the Devonian beds of Britain and Europe. The earliest remains found in Great Britain occur in the lowest Devonian, and also in the Upper Ludlow beds (p. 99).

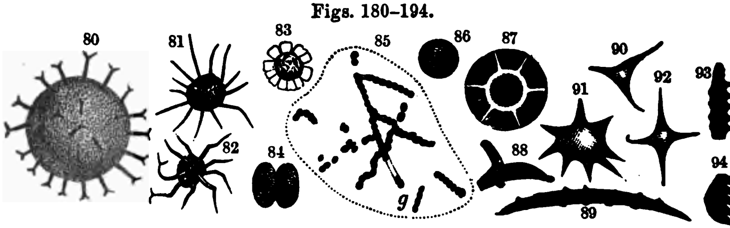
The hornstone develops, under the microscope, the fact that it was probably made from the siliceous remains of plants and animals. Figs. 180 to 194 represent some of the species which have been detected by Dr. M. C. White in specimens from New York and elsewhere. Figs. 180 to 186 are microscopic plants, related to the *Desmids;* fig. 187 is another kind, called a *Diatom*, a kind which forms siliceous shells, and which is probably one of the sources of the silica of which the hornstone was made. (See, on Diatoms and Desmids, p. 61.) Figs. 188, 189 are spicules of Sponges, also siliceous, and another of the sources of the silica. Figs. 190–192 are probably also sponge-spicules. Figs. 193, 194 are fragments of the teeth of some Gasteropod Mollusk. The last is from a hornstone of the Trenton period (Silurian) which was found to afford the same evidences of organic origin.

3. *Animals.*

The early Devonian was the coral period of the ancient world. In no age before or since, not even the present, have coral reefs of greater extent been formed.

Among Mollusks, Brachiopods were still the prevailing kinds, though ordinary Bivalves or Conchifers, and Uni-

Figs. 180–194.

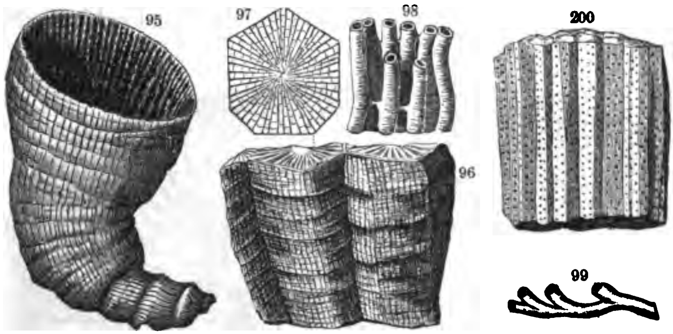


Microscopic Organisms from the Hornstone.

valves or Gasteropods, were more abundant than in the Silurian. A new type of Cephalopods commenced in the Middle Devonian. Hitherto, the partitions or septa in the shells, straight or coiled, were flat or simply concave; but in the new genus *Goniatites*, the margin of the plate has one or more deep angles, one of the angles being at the middle of the back of the shell. The name is from the Greek *gonu*, *knee* or *angle*.

Among Articulates, there were Worms and Crustaceans as in earlier time, and the most common Crustaceans were *Trilobites*. Besides these there were the first of Insects, the wings of some species having been reported from the Devonian of New Brunswick.

Figs. 195–200.



RADIATES.—Fig. 195, Zaphrentis Rafinesquii; 196, 197, Cyathophyllum rugosum; 198, Syringopora Maclurii; 199, Aulopora cornuta; 200, Favosites Goldfussi: all of the Corniferous period.

1. *Radiates.*—Fig. 195, one of the Cyathophylloid corals, *Zaphrentis Rafinesquii;* fig. 196, another, *Cyathophyllum rugosum*, both from the Falls of the Ohio, and the latter forming very large masses. Fig. 197 is a top view of the cells in fig. 196. Fig. 200, a *Favosites* from the same locality, showing well the columnar structure characterizing the genus: the species *F. Goldfussi* occurs both in America and Europe. Figs. 198 and 199 are small corals from Canada West.

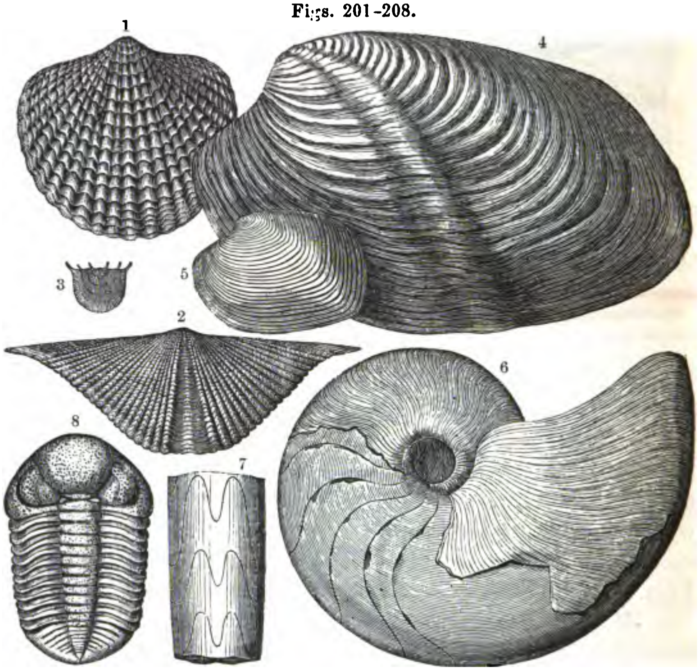
2. *Mollusks.*—Figs. 201 to 203, Brachiopods from the Hamilton beds; figs. 204, 205, Conchifers, from the same; fig. 206, *Goniatites Marcellensis*, ib.; fig. 207, a view of the back, showing the angles in the partitions, this species having only one angle or re-entering lobe.

3. *Articulates.*—Fig. 208, the Trilobite *Phacops Bufo.*

4. *Vertebrates.*—The fishes of the Devonian belong to two orders: the *Ganoid* and the *Selachian* (see p. 51). Some of the Ganoids are represented in figs. 210 to 216. The fishes of this order are related in several points to Reptiles. Unlike ordinary fishes (or the Teliosts)—(1) they have the power of moving the head up and down at the articulation between

the head and the body, the articulation being made by means of a convex and concave surface; (2) the air-bladder, which

Figs. 201-208.

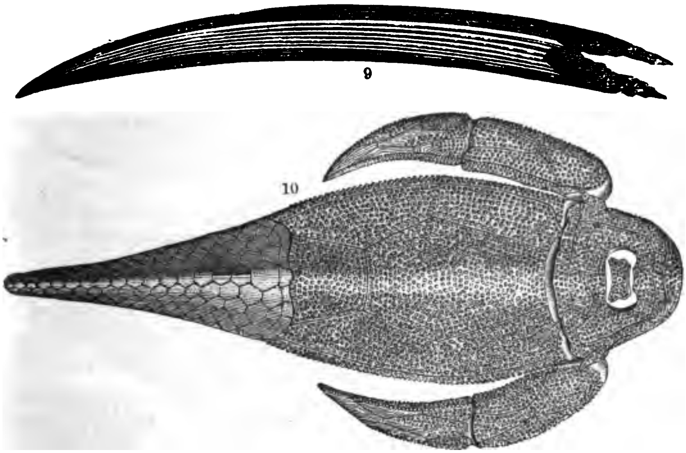


Mollusks.—Fig. 201, Atrypa aspera; 202, Spirifer mucronatus; 203, Chonetes setigera; 204, Grammysia Hamiltonensis; 205, Microdon bellistriatus; 206, 207, Goniatites Marcellensis: all from the Hamilton group. Articulates: Fig. 208, Phacops Bufo, from the Hamilton group.

answers to the lung of higher animals, has a cellular or lung-like structure, thus approximating to air-breathing species; (3) the teeth have in general a structure like that of some early Reptiles. Fig. 210 is a reduced view of a Ganoid with large plates over the body, like a Turtle: moreover, it moved by means of paddles instead of its tail, the principal organ of motion in most Fishes, and in this, also, it resembles

Turtles. It is the *Pterichthys* of Agassiz, a name signifying *winged fish.* There is another plate-covered kind, one genus

Figs. 209, 210.

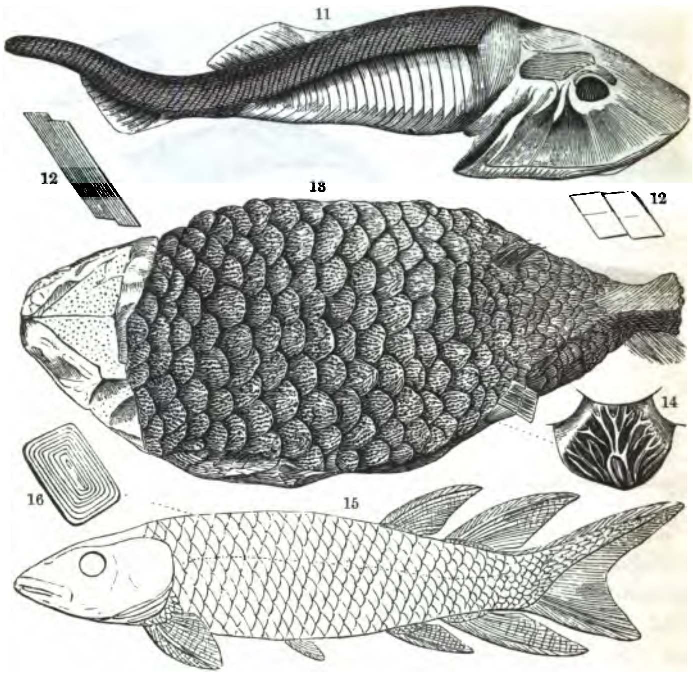


VERTEBRATES.—Fig. 209, Fin-spine of a Shark (×⅔); 210, Pterichthys Milleri (×⅔).

of which is named *Coccosteus*, which wants the paddles, and sculled itself along with the tail, like most Fishes. Fig. 211 represents a different type of Ganoid, the *Cephalaspis*, having a flat and broad plate-covered head, with rhombic scales over the body: figs. 212 show the forms of some of the scales. Fig. 215 is another, a species of *Dipterus*, covered with rhombic scales, put on, as in the preceding, much as tiles are arranged on a roof: fig. 216 is one of the scales, natural size. Fig. 213 is another type of Ganoids, having the scales rounded and set on more like shingles; it is a *Holoptychius*: fig. 214 represents a scale, natural size. These figures are all much reduced. Scales of a *Holoptychius* have been found in Chemung beds which were over an inch and a half broad, indicating the existence of fishes of great size.

The *Selachians*, or species of the shark tribe, belong to the family of *Cestracionts* (p. 52), or that in which the mouth

Figs. 211–216.



GANOIDS.—Fig. 211, Cephalaspis Lyellii ($\times \frac{2}{3}$); 212, Scales; 213, Holoptychius ($\times \frac{1}{7}$); 214, Scale; 215, Dipterus macrolepidotus ($\times \frac{1}{2}$); 216, Scale.

has a pavement of broad bony pieces for grinding. The food in the seas for these carnivorous Fishes consisted mainly of shell-fish and mail-clad Ganoids; and grinders were, therefore, better suited for the times than cutting teeth. Many of these Cestraciont sharks were of very large size. Fig. 209 represents a fin-spine of one, *drawn two-thirds* its actual size, found in the Corniferous beds of the State of New York.

The remains of Fishes in the rocks are numerous after the first appearance of them.

4. General Observations.

1. **Geography.**—During the Silurian there had been a gradual gain of dry land on the north, extending the Azoic continent (p. 73) southward. This gain continued through the Devonian, so that the beds of the next age, the Carboniferous, extend only a short distance north of the southern boundary of New York. The sea-shore was thus being set farther and farther southward with the progressing periods.

The formations have their greatest thickness along the Appalachian region, as in the Silurian Age. And both this fact and their successions lead to similar general conclusions to those stated on page 102.

2. **Life.**—The great feature of the Devonian age is the introduction of the first of terrestrial plants, the first of terrestrial animals (Insects), and the first of Vertebrates. It is possible that future discovery may throw farther back in time the commencement of these types. However this may be, whenever the first land-plant appeared, it was an epoch of great progress in the system of life on the earth. It was a change from the leafless Sea-weed to Ferns, Lepidodendra, and Pines,—from a bare and lifeless world above tide-level to one of forest-clad hills.

This step of progress from Sea-weeds to Ferns, Lycopodia, and Pines was not made by a gradual working upward through Mosses and other low forms of Cryptogams. On the contrary, no Mosses, although many are true marsh-species, appear to have been in existence until long after the close of the Carboniferous age. It was a sudden advance from the lowest to the highest of Cryptogams.

In the same manner, with regard to Fishes, the earliest species belong to the two highest groups of the class,—the Sharks and Ganoids; and both are above the level of the fish,—the Ganoids being partly Reptilian. There is not the least evidence of any development upward from the Mollusk, Worm, or Trilobite to these Fishes, or of a gradual rise in the grade of Fishes from the lower to the highest. The Devonian Fishes are often of great size and eminently complete and perfect in their parts. Their introduction into the system of life was a no less sudden step upward than in the case of plants.

There are here no facts sustaining the theory that species were made from species by a natural process of growth or development. Without any known natural method of creation to appeal to, Science is led rightly to ascribe the existence of plants and animals, each in its time and place, to Him alone who created "in the beginning."

III. CARBONIFEROUS AGE, OR AGE OF COAL PLANTS.

1. General Characteristics: Subdivision.

The Carboniferous age was remarkable, in general, for—

(1.) The wide limits of the continents above the sea-level.

(2.) The extent of the low marshy or fresh-water areas over these continents, and the flat or gently undulating surface of nearly all the rest of the emerged land, few elevated ridges existing any where.

(3.) The luxuriant vegetation, clothing the land with forests and jungles.

(4.) The existence of Insect life over the land, and of Amphibians and other Reptiles in the marshes and seas.

But, while having these as its main characteristics, it was not an age of continued verdure. There was, first, a long period—the *Subcarboniferous*—in which the land was mostly beneath the sea; for limestone, full of marine fossils, is the prevailing rock, and there are but thin coal seams in some regions of sandstones and shales. This period was followed by the *Carboniferous*, or that of the true Coal measures. Yet even in this middle period of the age there were alternations of submerged with emerged continents, long eras of dry and marshy lands luxuriantly overgrown with shrubbery and forest-trees intervening between other long eras of great barren continental seas. Then there was a closing period,—the *Permian*,—in which the ocean prevailed again, though with contracted limits; for the rocks are mainly of marine origin.

The Carboniferous period and age were so named from the fact that the great coal beds of the world originated mainly during their progress. The term *Permian* was given to the rocks of the third period by Murchison, de Verneuil and Keyserling, from a region of Permian rocks in Russia, the ancient kingdom of Permia, now divided into the governments of Perm, Viatka, Kasan, Orenberg, etc.

2. Distribution of Carboniferous Rocks.

The Carboniferous areas on the map of the United States, p. 69, are the dark areas; the black cross-lined with white being the *Subcarboniferous;* the pure black, the *Carboniferous;* the black dotted with white, the *Permian.* The last occur only west of the Mississippi.

The following are the positions of the several great areas in North America:—

I. Eastern Border Region.—(1.) The *Rhode Island* area, extending from Newport in Rhode Island to Worcester in Massachusetts.

(2.) The *Nova Scotia and New Brunswick* area.

II. Appalachian and Interior Regions.—(1.) The great *Appalachian* area, extending from the southern borders of New York and Ohio southwestward to Alabama, covering the larger part of Pennsylvania, half of Ohio, part of

Kentucky and Tennessee, and a little of Mississippi. To the northeast, in Pennsylvania, this coal field is much broken into patches, as shown in the accompanying map of

Fig. 219.

Map of part of Pennsylvania, showing the Coal areas of the State, *in black*; also the Mesozoic red sandstone formation, *obliquely lined across*.

a part of the State, the black areas being those of the coal district.

(2.) The *Michigan* area, covering the central part of the State.

(3.) The *Illinois and Missouri* area, or that of the Mississippi basin, covering much of Illinois, and part of Indiana, Kentucky, Iowa, Minnesota, Missouri, Kansas, and Arkansas, and stretching southward into northern Texas.

(4.) The *Rocky Mountain* area, situated in some parts of the summits of the Rocky Mountains, as around the Great Salt Lake in Utah.

III. Arctic Region.—The Melville Island, and those of other islands between Grinnell Land and Banks Land, mostly north of latitude 70°.

The areas of workable coal measures are estimated as follow:—

1. Rhode Island	1,000	square miles.
2. Nova Scotia and New Brunswick	18,000	" "
3. Appalachian	60,000	" "
4. Michigan	5,000	" "
5. Illinois and Missouri	60,000	" "

The total for the whole United States is about 130,000 square miles.

Carboniferous strata occur also in Great Britain and various parts of Europe. Those of England are distributed over an area between South Wales on the west and the Newcastle basin on the northeast coast (as shown by the black areas on the following map), the most important for coal being the South Wales region; the Lancashire district, bordering on Manchester and Liverpool; the Yorkshire, about Leeds and Sheffield; and the Newcastle.

Scotland has some small areas between the Grampian range on the north and the Lammermuirs on the south; and Ireland, several coal regions of large extent, as at Ulster, Connaught, Leinster (Kilkenny), and Munster.

The coal-fields of Europe which are most worked are the Belgian, bordering on and passing into France. Germany contains only small coal-bearing areas; and Russia in Europe

Fig. 218.

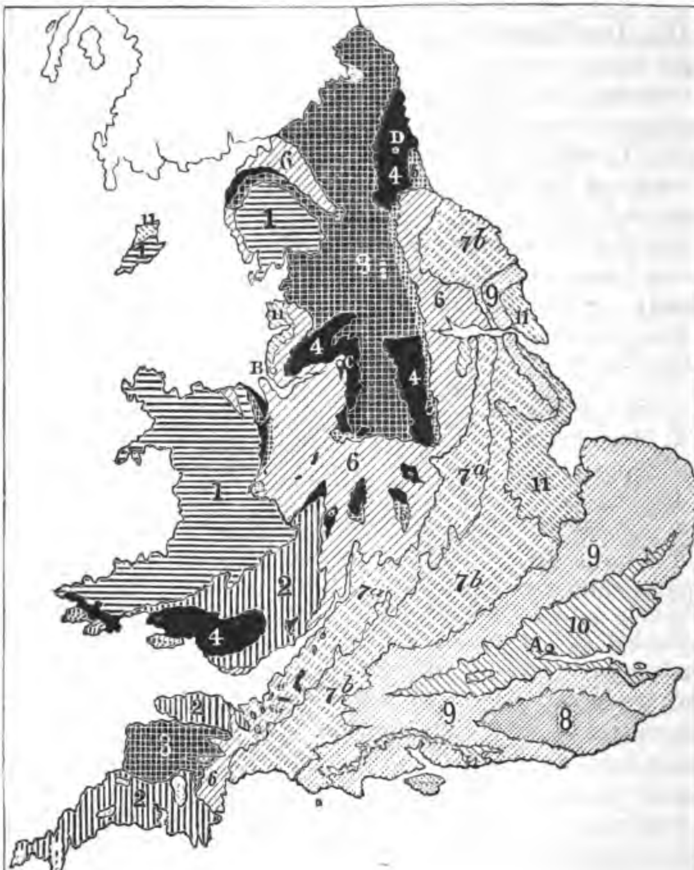


Fig. 218, Geological Map of England. The areas lined horizontally and numbered 1 are Silurian. Those lined vertically (2), Devonian. Those cross-lined (3), Subcarboniferous. Carboniferous (4), black. Permian (5). Those lined obliquely from right to left, Triassic (6), Lias (7 *a*), Oolite (7 *b*), Wealden (8), Cretaceous (9). Those lined obliquely from left to right (10, 11), Tertiary. A is London, B, Liverpool, C, Manchester, D, Newcastle.

almost none, although the Subcarboniferous and Permian rocks cover large portions of the surface.

The following are the areas of some of the foreign coal districts :—

Great Britain and Ireland..........	12,000	square miles.
Spain....................................	4,000	" "
France..................................	2,000?	" "
Belgium................................	518	" "

or less than 20,000 square miles, against 148,000 in North America.

Valuable coal beds are not found in any rocks older than the Carboniferous, although black bituminous slates are not uncommon even in the Lower Silurian. They occur, however, in different Mesozoic formations, and also occasionally in the Cenozoic, but not of the extent which they have in the Carboniferous formations.

3. Kinds of Rocks.

1. Subcarboniferous Period.—The Subcarboniferous strata in the *Interior Continental* region are mainly limestone; and, as the limestone abounds in many places in Crinoidal remains, the rock is often called the *Crinoidal limestone*. In the *Appalachian region*, in middle and southern Virginia, the rock is also limestone, and has great thickness; but in northern Virginia and Pennsylvania it is mostly a sandstone or conglomerate overlaid by a shaly or clayey sandstone and marlite of reddish and other colors,—the whole having a maximum thickness of 5000 to 6000 feet. In the *Eastern border region*, in Nova Scotia, the rocks are mostly reddish sandstone and marlite, with some limestone,—the estimated thickness 6000 feet.

The prevailing rock in Great Britain and Europe is a limestone, called there the Mountain limestone.

2. Carboniferous Period.—(1.) *Rocks of the Coal formation.*—The rocks of the Carboniferous period—that is, those

of the Coal measures—are sandstones, shales, conglomerates, and occasionally limestones; and they are so similar to the rocks of the Devonian and Silurian ages that they cannot be distinguished except by the fossils. They occur in various alternations, with an occasional bed of coal between them. The coal-beds, taken together, make up not more than *one-fiftieth* of the whole thickness; that is, there are 50 feet or more of barren rock in the coal formation to 1 foot of coal.

An example of the alternations is given in the following section:—

1.	Sandstone and conglomerate beds	120 feet.
2.	COAL	6 "
3.	Fine-grained shaly sandstone	50 "
4.	*Siliceous iron-ore*	1½ "
5.	Argillaceous sandstone	75 "
6.	COAL, upper 4 feet shale, with fossil plants, and below a thin clayey layer	7 "
7.	Sandstone	80 "
8.	*Iron-Ore*	1 "
9.	Argillaceous shale	80 "
10.	LIMESTONE (oolitic), containing *Producti, Crinoids*, etc.	11 "
11.	*Iron-Ore*, with many fossil shells	3 "
12.	Coarse sandstone, containing trunks of trees	25 "
13.	COAL, lying on 1 foot slaty shale with fossil plants	5 "
14.	Coarse sandstone	12 "

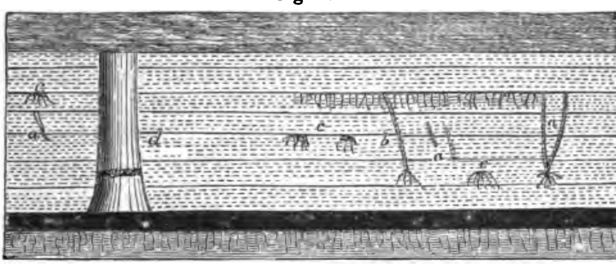
The limestone strata are more numerous and extensive in the *Interior Continental* region than in the *Appalachian*, and west of the States of Missouri and Kansas limestone is the prevailing rock.

Beds of argillaceous iron-ore are very common in coal districts, so that the same region affords ore and the coal for smelting it. Some of the largest iron-works in the world, on both sides of the Atlantic, occur in coal districts.

The coal beds often rest on a bed of grayish or bluish clay, called the *under-clay*, which is filled with the roots or stems of plants. When this under-clay is absent, the rock is usually a sandstone or shale. Above the coal, the rock may be sandstone, shale, conglomerate, or even limestone; often the layer next above, especially if shaly, is filled with fossil leaves and stems. In some cases, trunks of old trees rise from the coal and extend up through overlying beds, as in the annexed figure, by Dawson, from the Nova Scotia Coal measures. Occasionally, as in Ohio, logs 50 to 60 feet long lie scattered through the sandstone beds, looking as if a forest had been swept off from the land into the sea.

(2.) *Coal beds.*—The coal beds vary in thickness from a fraction of an inch to 30 or 40 feet, but seldom exceed 8 feet,

Fig. 219.



Section of a portion of the Coal measures at the Joggins, Nova Scotia, having erect stumps, and also "rootlets" in the under-clays.

and are generally much thinner: 8 feet is the thickness of the principal bed at Pittsburg, Pa.; 29½ feet, that of the "Mammoth Vein" at Wilkesbarre, Pa.; 37½ feet, that of one of the two great beds at Pictou in Nova Scotia. In these thick beds, and often also in the thin ones, there are some intervening beds of shale, or of very impure coal, so that the whole is not fit for burning.

The coal varies in kind according to the proportion of bituminous substances present,—that containing little or none being called *Anthracite*, and the rest *Bituminous coal* (see p. 18). When only 10 or 15 per cent. of bituminous substances are present, it is often called *Semi-bituminous* coal. In Pennsylvania the coal of the Pottsville, Lehigh, and Wilkesbarre regions is *anthracite;* that of Pittsburg, *bitumi-*

nous coal; and that of part of the intermediate district, *semi-bituminous*, as so designated on the map, page 118.

The coal also varies as to the impurities present. All of it contains more or less of earthy material, as clay or silica; and this earthy material constitutes the ashes and slag of a coal fire. Ordinary good anthracite contains 7 to 12 pounds of impurities in a hundred pounds of coal. In some coal beds there is considerable pyrites or sulphuret of iron (a compound of sulphur and iron), and the coal is then unfit for use. It is seldom that pyrites is altogether absent. The sulphur gases which are perceived in the smoke or gas from a coal fire come usually from the decomposition of pyrites.

Mineral coal, although it seldom breaks into plates unless quite impure, still consists of thin layers. This is shown in the hardest anthracite by a delicate banding of a surface of fracture, as may be readily seen when it is held up to the light. This structure is absent in the variety called *Cannel* coal, which is a bituminous coal, very compact in texture, feeble in lustre, and smooth and often flint-like in fracture.

(3.) *Mineral Oil.*—Besides mineral coal, the rocks sometimes afford bituminous liquids, called ordinarily *petroleum*, or *mineral oil*, or, when purified for burning, *kerosene*, and sometimes *mineral naphtha.* Oil-wells are largely worked at Titusville in Pennsylvania, and at Mecca in Trumbull co., Ohio; and it is probable that the material at each of these places proceeds from the lower Subcarboniferous rocks, though possibly from the Devonian. Petroleum is a result of the decomposition of vegetable substances. It proceeds from rocks of various ages,—from those of the Lower Silurian to the Tertiary. The earliest springs affording a large supply of oil come from the Corniferous beds (Devonian), as at Enniskillen in Canada.

(4.) *Salt or Salines.*—The Subcarboniferous formation in Michigan, at Grand Rapids and the adjoining region, affords extensive salines, and there are many wells opened by boring. The beds affording the saline waters consist of clayey beds or marlites, shale, and magnesian limestone, and abound also in gypsum, thus resembling those of the Salina period in New York (p. 95).

3. PERMIAN PERIOD.—The rocks of the Permian beds are mostly sandstones and marlites, with some impure or magnesian limestones, and gypsum. They occur in North America west of the Mississippi in Kansas, and about some parts of the eastern slope of the Rocky Mountains, where they lie conformably over the Carboniferous. Similar rocks occur in Great Britain in the vicinity of several of the coal regions, and also in Germany and Russia. Thin seams of coal are occasionally interstratified with the sandstones, but none of workable extent are known.

4. Life.

1. *Plants.*

The plants of the forests, jungles, and floating islands of the Carboniferous Age, thus far made known, number about 900 species. Among the fossils there are none that afford satisfactory evidence of the presence of either *Angiosperms* or *Palms* (p. 62); for no net-veined leaves, allied in character to those of the *Oak*, *Maple*, *Willow*, *Rose*, etc., have been found among them; and no *palm-leaves* or *palm-wood.* Moreover, the plains were without grass, and the swamps and woods without moss. At the present day Angiosperms, along with Conifers, or the Pine family, make up the great bulk of our shrubs and forest-vegetation; Palms abound in all tropical countries; grass covers all exposed slopes where the climate is not too arid; and mosses are the principal vegetation of most open marshes.

The view in fig. 220 gives some idea of the Carboniferous vegetation over the plains and marshes of the era.

The Carboniferous species, like their predecessors in the Devonian age, belonged to the following groups:—

I. Cryptogams, or Flowerless Plants, Order of Acrogens.

(1.) *Fern tribe.*—Ferns were very abundant, a large part of the fossil plants of a coal region being their delicate fronds

Fig. 220.

Carboniferous Vegetation.

(usually called leaves). One of them is represented in fig. 224. Besides small species, like the common kinds of the present day, there were *tree-ferns*, species that had a trunk, perhaps 15 or 20 feet high, and which bore at top a radiating tuft of the very large leaf-like fronds, resembling the modern tree-fern of the tropics. One of the tree-ferns of the Pacific is represented in fig. 220, near the middle of the view, and smaller ferns in front of it below. Tree-ferns, however,

Figs. 221-226.

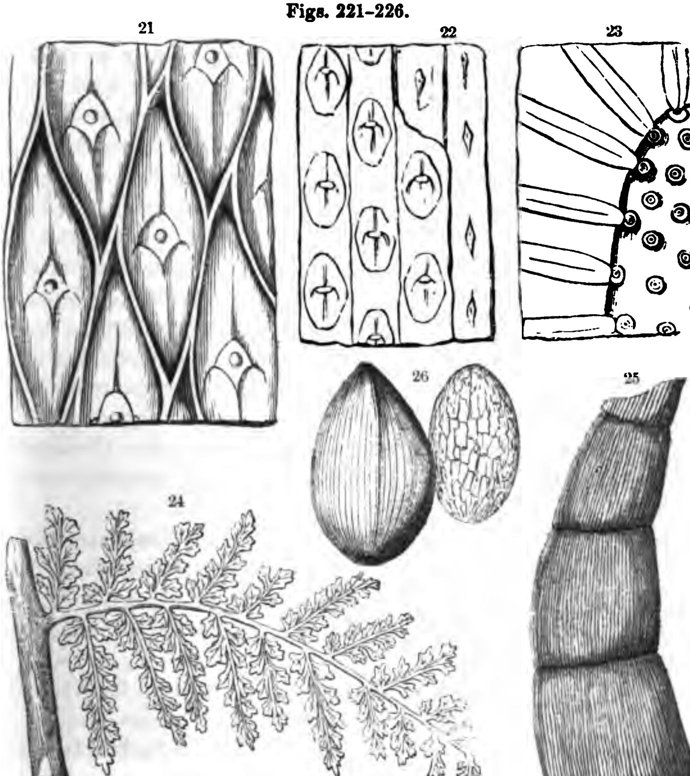


Fig. 221, Lepidodendron obovatum; 222, Sigillaria oculata; 223, Stigmaria ficoides; 224, Sphenopteris Gravenhorstii; 225, Calamites cannæformis; 226, Trigonocarpum tricuspidatum.

were not common in the Carboniferous forests. The scars in fossil or recent tree-ferns are many times larger than those of Lepidodendra, and the fossils may be thus distinguished.

(2.) *Lycopodium tribe.*—The Lepidodendra appear to have been among the most abundant of Carboniferous forest-trees, especially in the earlier half of the Carboniferous Age, or to the middle of the Coal Period. They probably covered both the marshes and the drier plains and hills. Some of the old logs now preserved in the strata are 50 to 60 feet in length; and the pine-like leaves were occasionally a foot or more long. The taller tree to the left, in figure 220, is a Lepidodendron. Figure 221 shows the surface-markings of one of the species, natural size: the regular arrangement of the scars resembles a little the arrangement of scales on a fish, and this gave origin to the name *Lepidodendron*, from the Greek *lepis*, *scale*, and *dendron*, *tree*.

(3.) *Equisetum tribe.*—Fig. 225 represents a portion of one of the tree-rushes, or *Calamites*, usually regarded as of the Equisetum tribe. The species were evidently very abundant in the great marshes, through the whole of the Carboniferous Age; some were 20 feet or more high, and 10 or 12 inches in diameter.

Besides these Cryptogams there were also *Fungi*, or *Mushrooms;* but, as already stated, no remains of Mosses from the rocks of the age are known.

II. PHENOGAMS, or Flowering Plants, Order of GYMNOSPERMS.

(1.) *Conifers.*—Trunks of trees, supposed to be Coniferous in character, and related especially to the *Araucarian* pines, are common. As stated on p. 109, they may be the trunks of *Sigillarids*; yet this is not probable.

(2.) *Sigillarids.*—The *Sigillariæ* were a very marked feature of the great jungles and damp forests of the Coal period. They grew to a height sometimes of 30 to 60 feet; but the trunks were seldom branched, and must have had a stiff, clumsy aspect, although covered above with long, slender, rush-like leaves. Fig. 222 represents a common species, exhibiting the usual arrangement of the scars in vertical lines, and also indicating, by the difference in the scars of the right row from those of the others, the difference of form on the inside and outside of the bark.

(3.) *Stigmariæ.*—The fossil *Stigmariæ* are stout stems, generally 2 to 3 or more inches thick, having over the surface distant rounded punctures or depressions.

Fig. 223 is a portion of the extremity of a stem, showing the rounded depressions and also the leaf-like appendages occasionally observed. The stems or branches are a little irregular in form, and sparingly branched. They have been found spreading, like roots, from the base of the trunk of a *Sigillaria*, and sometimes also from that of a *Lepidodendron;* and they are hence regarded either as the roots or subaqueous stems of these trees. They are an exceedingly common fossil, especially in the under-clays of the Coal measures (p. 122). If they are roots, they indicate that the under-clay, as stated by Logan, was the old *dirt-bed* in which the vegetation that gave rise to a bed of coal first took root. If subaqueous stems, as Lesquereux believes them to have often been, they grew and spread through the shallow waters, and formed the basis of floating vegetation, while the clay was accumulating over the bottom, like the fireclay beneath a modern peat-bed.

In the Carboniferous landscape, fig. 220, p. 126, the broken trunk to the right is a *Sigillaria*. The landscape, to be quite true to nature, should have been made up largely of *Sigillariæ*, *Calamites*, and *Lepidodendra*, with few tree-ferns. The Stigmariæ would have been mostly concealed beneath the water or soil, or in the submerged mass of the floating islands.

(4.) *Fruits.*—Besides the leaves, stems, and trunks already alluded to, there are various nut-like fruits found in the Carboniferous strata. One is represented in fig. 226, the figure to the left being that of the shell, and the other that of the nut which it contained. Some of them are two inches in length. The most of them were probably the fruit of *Sigillariæ* or *Conifers;* some, perhaps, of the *Lepidodendra.*

(5.) *Conclusions.*—It is seen from the above that—

(1.) The vegetation of the Carboniferous age consisted very largely of Cryptogams, or flowerless plants.

(2.) The flowering plants, or Phenogams, associated with the flowerless vegetation, were of the order of Gymnosperms, whose flowers are incomplete and inconspicuous.

(3.) While, therefore, there was abundant and beautiful foliage (for no foliage exceeds in beauty that of Ferns), the vegetation was nearly flowerless.

(4.) The characteristic Cryptogams were not only of the highest group of that division of plants, but in general they exceeded in size and perfection the species of the present day, many being forest-trees.

2. *Animals.*

The principal steps of progress in animal life have already been in part pointed out,—viz. the increase in the variety and number of land-Articulates; there being *Myriapods* (or Centipedes) and *Scorpions*, as well as *Insects;* and the rise in Vertebrates from water-Vertebrates, or *Fishes*, to *Reptiles.*

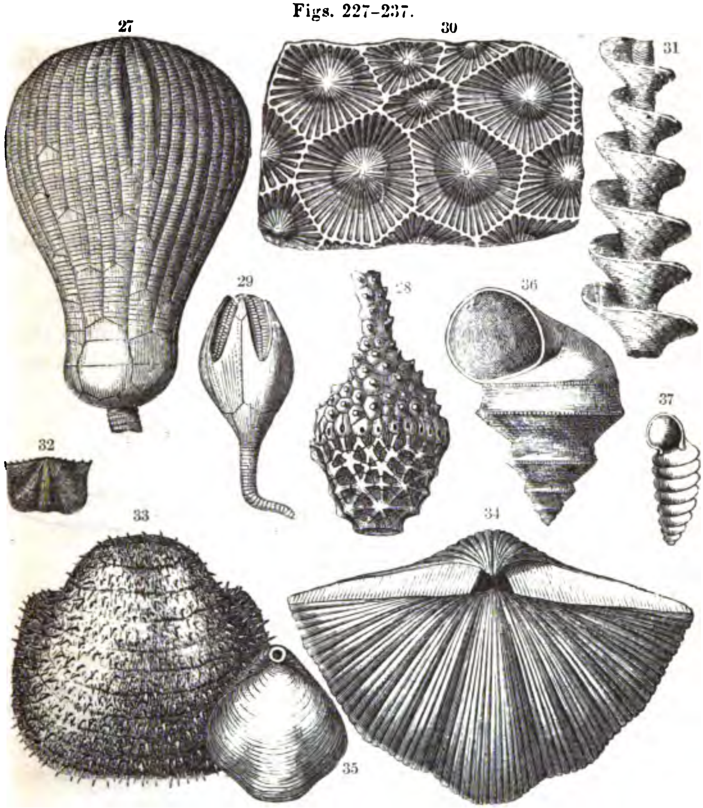
1. *Radiates.*—Among Radiates, species of Crinoids were especially numerous and varied in form in the Subcarboniferous period. Figs. 227 to 229 represent some of the species. The radiating arms are perfect in fig. 227, but wanting in 228. Fig. 229 is a species of the genus *Pentremites* (named from the Greek *pente*, *five*, alluding to the five-sided form of the fossil). The Pentremites had a long stem made of calcareous disks, like other Crinoids, but no long radiating arms at top.

Fig. 230 presents an upper view of a very common Coral of the same period: it has a columnar appearance in a side view.

2. *Mollusks.*—The tribe of Bryozoans contained the sin-

gular screw-shaped (or auger-shaped) coral shown in fig. 231, and named *Archimedes* (referring to Archimedes' screw). It

Figs. 227–237.



RADIATES: Fig. 227, Zeacrinus elegans; 228, Actinocrinus proboscidialis; 229, Pentremites pyriformis; 230, Lithostrotion Canadense.—MOLLUSKS: Fig. 231, Archimedes reversa; 232, Chonetes mesoloba; 233, Productus Rogersi; 234, Spirifer cameratus; 235, Athyris subtilita; 236, Pleurotomaria tabulata; 237, Pupa vetusta.

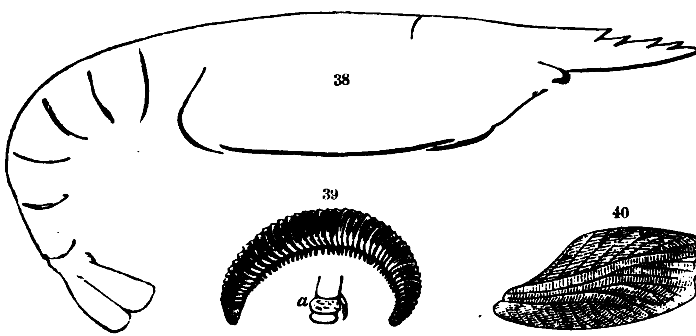
is made up of minute cells that open over the lower surface; each of the cells, when alive, contained a minute Bryozoan

(p. 57). These fossils are common in some of the Subcarboniferous limestone strata.

Brachiopods were the most abundant of Mollusks through the Carboniferous age, and especially species of the genera *Spirifer* and *Productus*. Figures 232 to 235 are of species from the American Coal measures: fig. 234, a *Spirifer;* fig. 233, a *Productus;* fig. 232, a *Chonetes;* fig. 235, an *Athyris*, occuring also in Europe. Fig. 236 represents one of the Gasteropods of the Coal measures. Fig. 237 is a *Pupa*, the *first yet known* of land-snails: it is from the Coal measures of Nova Scotia. The order of Cephalopods contained but few and small species of the old tribe of *Orthocerata*, but many of the Ammonite-like *Goniatites.*

3. *Articulates.*—Among *Articulates*, Crustaceans appeared under a new form, much like that of modern shrimps (fig. 238, from Scotland), and *Trilobites* were of rare occurrence.

Figs. 238–240.



CRUSTACEAN: Fig. 238, Anthracopalæmon Salteri.—MYRIAPOD: Fig. 239 *a*, Xylobius Sigillariæ.—INSECT-WING: Fig. 240, Blattina venusta.

Fig. 239 represents a Myriapod resembling a modern *Iulus*, from Nova Scotia; 239 *a*, shows the organs of the mouth, as they are still preserved in the specimen.

Fig. 240 is a wing of an Insect of the genus *Blattina*, related to the modern Cockroach (or *Blatta*), drawn from a specimen obtained in the Coal measures of Arkansas. There were also species of *Neuropterous* insects, of *Locusts* (or Orthopterous insects) and *Beetles* (or Coleopters), besides *Scorpions* (of the class of Spiders).

4. *Vertebrates.*—Fishes were numerous, both of the orders of Ganoids and Selachians. All the Ganoids were of the ancient type, having the caudal fin vertebrated (or heterocercal), as in the *Palæoniscus*, represented in fig. 241, a Permian species. Many of the Selachians, or Sharks, were of great size, as shown by the fin-spines. Fig. 242 represents a small portion of one of these spines, natural size, from the Subcarboniferous beds of Europe. One of the largest specimens of the same species thus far found had a length

Figs. 241, 242.

Fig. 241, Palæoniscus Freieslebeni (× 1/3); 242, Part of a spine of Ctenacanthus major.

of 14½ inches, and when entire it must have been full 18 inches long.

The first traces of Reptiles yet known occur in the Subcarboniferous beds of Pottsville, Pennsylvania.

Figs. 243–245.

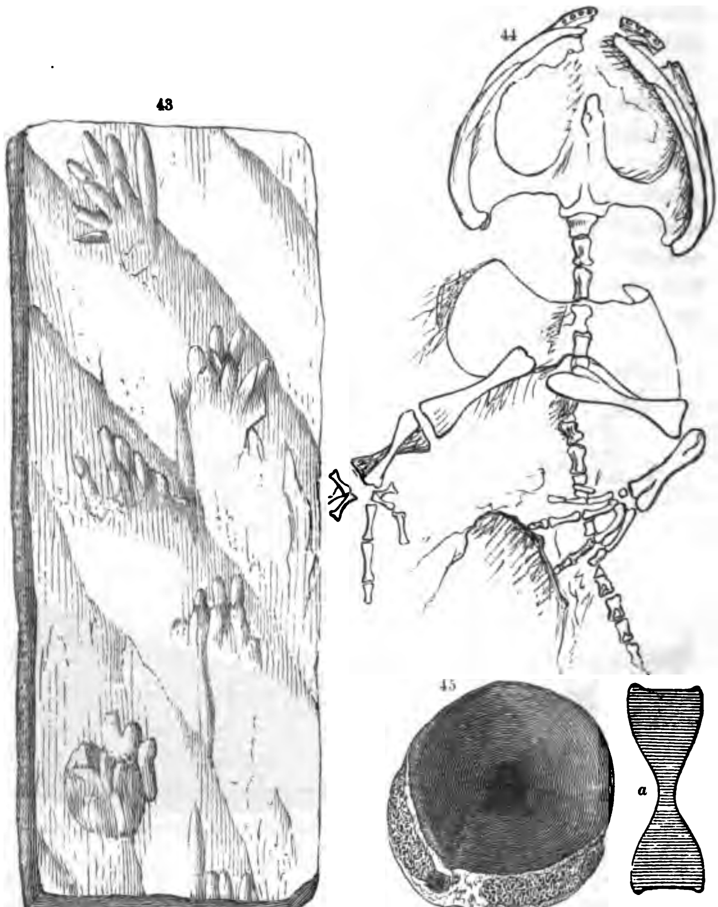


Fig. 243, Tracks of Sauropus primævus (× 1/8); 244, Raniceps Lyellii; 245 *a*, Vertebra of Eosaurus Acadianus.

Fig. 243 is a reduced sketch of a slab containing tracks of the species, and also an impression left by the tail of the animal. The tracks of the fore-feet, as described by I. Lea, are 5-fingered and 4 inches broad, and those of the hind feet 4-fingered and nearly of the same size; while the stride indicated was 13 inches. Fig. 244 represents a skeleton of an Amphibian from the Ohio Coal measures, found by Newberry; and fig. 245 a vertebra of a swimming Saurian probably related to the Enaliosaurs, or Sea-Saurians, of the Mesozoic (see p. 180), discovered by Marsh in the Coal measures of Nova Scotia. This vertebra is concave on both surfaces, as shown in the section in fig. 245 *a*, and in this respect resembles those of fishes. The Enaliosaurs had paddles like Whales.

These Enaliosaurs, or swimming Reptiles, are the highest species of animal yet discovered in rocks of the Carboniferous period. In the Permian period there were still higher Reptiles, called Thecodonts (because the teeth are set in sockets, from the Greek *theca*, *case*, and *odous*, *tooth*). But these also had the fish-like characteristic of doubly-concave vertebræ.

5. General Observations.

1. Formation of Coal and the Coal measures.—(1.) *Origin of the Coal.*—The vegetable origin of coal is proved by the following facts:—

(1.) Trunks of trees, retaining still the original form and part of the structure of the wood, have been found changed to mineral coal, both in the Carboniferous and more modern formations, showing that the change may and does take place.

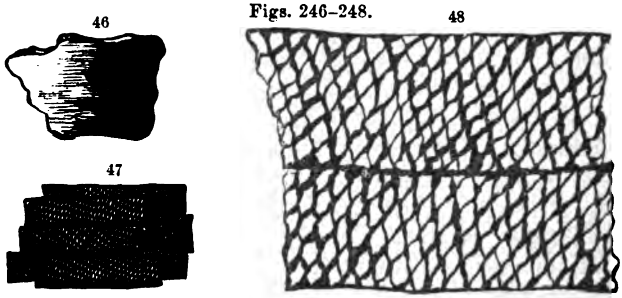
(2.) Beds of peat, a result of vegetable growth and accumulation, exist in modern marshes; and in some cases they are altered below to an imperfect coal (see page 263 on the formation of peat).

(3.) Remains of plants, their leaves, branches, and stems or trunks, abound in the Coal measures; trunks sometimes extend upward from a coal-bed into and through some of the overlying beds of rock; roots or stems abound in the under-clays.

(4.) The hardest anthracite contains throughout its mass vegetable tissues. Prof. Bailey examined with a high magnifying power several pieces of anthracite burnt at one end, like fig. 246, taking fragments from the junction of the white and black portion, and detected readily the tissues. Figure 247 represents the ducts, as they appeared in one case under his microscope; and fig. 248 part of the same, more magnified.

(2.) *Decomposition of Vegetable Material.*—Carbon, the essential element of mineral coal, exists as one of the constituents of all wood or vegetable material, making up 49 per cent. (or nearly one-half) of dry wood; and to obtain this carbon as coal it is necessary only to expel the other constituents

Figs. 246–248.



of the wood,—that is, the gases *oxygen* and *hydrogen.* Vegetable matter decomposing in the open air—like wood burnt in an open fire—passes, carbon and all, into gaseous combinations, and little or no carbon is left behind. But when it is decomposed slowly under water, or by a slow, half-smothered fire, only part of the carbon is lost in gaseous combinations, the rest remaining as coal,—called *mineral coal* in the former case, and *charcoal* in the latter.

The actual loss, by weight, in the transformation into bituminous coal, is at least *three-fourths* of the *wood*, and in that into anthracite, *five-sixths*. Adding to this loss that from compression, by which the material is brought to the density of mineral coal, the whole reduction in bulk is not less than *seven-eighths* for the former, and *eleven-twelfths* for the latter. In other words, it would take 8 feet of vegetable matters to make 1 of bituminous coal, and 12 feet to make 1 of anthracite.

(3.) *Impurities in Coal.*—The coal thus formed contains the silica existing in minute quantities in vegetable substances, and also other earthy materials that are not carried away in solutions. By this means, and through the addition of clay or earth, introduced by waters or by the winds, the coal has derived the earthy impurities which give rise to the ashes and slag formed in a hot fire.

(4.) *Accumulation and Formation of Coal-beds.*—The origin of coal-beds was, then, as follows:—The plants of the great marshes and shallow lakes of the Coal era, the latter with their *floating islands* of vegetation, continued growing for a long period, dropping annually their leaves, and from time to time decaying stems or branches, until a thick accumulation of vegetable remains was formed,—probably 8 feet in thickness for a one-foot bed of bituminous coal, or over 60 feet for such a bed as that of the Pittsburg region (p. 123). The bed of material thus prepared over the vast wet areas of the continent early commenced to undergo at bottom that slow decomposition the final result of which is mineral coal. But, as the coal-beds alternate with sandstones, shales, conglomerates, and limestones, the long period of verdure was followed by another of overflowing waters,—and generally oceanic waters, as the fossils prove,—which carried sands, pebbles, or earth over the old marsh, till scores or hundreds of feet in depth of such deposits had been made. Thus, the bed of vegetable debris was buried where the process of decomposition proper for making coal could still go on to its completion; for it would have the smothering influence of the burial, as well as the presence of water, to favor the process.

(5.) *Climate of the Age.*—The wide distribution of the coal regions over the globe, from the tropics to the remote Arctic, and the general similarity of the vegetable remains in the coal-beds of these remote zones, prove that there was a general uniformity of climate over the globe in the Carboniferous age, or at least that the climate was nowhere colder than *warm-temperate.* Similar corals and shells existed during the Subcarboniferous period in Europe, the United States, and the Arctic within 20° of the north pole, and so profusely as to form thick limestones out of their accumulations. The ocean's waters, even in the Arctic, were, therefore, warm compared with those of the modern temperate zone, and probably quite as warm as the coral-reef seas of the present age, which lie mostly between the parallels of 28° either side of the equator.

(6.) *Atmosphere.*—The atmosphere was especially adapted for the age in other respects. It contained a larger amount than now of carbonic acid gas,—the gas which promotes (if not in excess) the growth of vegetation. Plants derive their carbon mainly from the carbonic acid of the atmosphere; and hence the mineral coal of the world is approximately a measure of the amount of carbonic acid the atmosphere in the Carboniferous era lost. The growth of the flora of that age was a means of purifying the atmosphere so as to fit it for the higher terrestrial life that was afterwards to possess the world.

Again, the atmosphere was more *moist* than now. This follows from the greater heat of the climate and the greater extent as well as higher temperature of the oceans.

The continents, although large during the intervals of verdure compared with the areas above the ocean in the Devonian or Silurian, were still small and the land low. It must, therefore, have been an era of prevailing clouds and mists. A moist climate would not, however, have been universal, as even the ocean has now its great areas of drought depending on the courses of the winds. America is now the moist forest-continent of the globe; and the great extent of the coal-fields of its northern half proves that it bore the same character in the Carboniferous age.

2. **Geography.**—(1.) *Appalachian and Rocky Mountains not made.*—On page 116 it is stated that the continents in this age were low, with few mountains. The non-existence of the Appalachians of Pennsylvania and Virginia is proved by the fact that the rocks of these mountains are to a considerable extent Carboniferous rocks;—partly *marine* rocks, indicating that the sea then spread over the region where they now lie; partly *coal-beds*, each bed evidence that a great fresh-water marsh, flat as all marshes are, for a long while occupied the region of the present mountains.

There is the same evidence that the mass of the Rocky Mountains had not been lifted; for marine Carboniferous rocks constitute a large part of these mountains, many beds containing remains of the life of the Carboniferous seas that covered that part of North America. Only islands, or archipelagos of islands, made by some Azoic and Paleozoic ridges, existed in the midst of the wide-spread western waters.

(2.) *Condition in the Subcarboniferous Period.*—Through the first period of this age—the Subcarboniferous—the continent was almost as extensively beneath the sea as in the Devonian age. This, again, is shown by the nature and extent of the Subcarboniferous rocks,—the great crinoidal limestones. The shallow continental seas were profusely planted with Crinoids amid clumps of Corals. Brachiopods were here and there in great abundance, many lying together in beds as oysters in an oyster-bed; other Mollusks, both Conchifers and Gasteropods, were also numerous; Trilobites were few; Goniatites and Nautili, along with Ganoid Fishes and sharks, were the voracious life of the seas, and Amphibian reptiles haunted the marshes.

(3.) *Transition to the Carboniferous Period.*—Finally, the Subcarboniferous period closed, and the Carboniferous opened. But in the transition from the period of submergence to that of emergence required to bring into existence the great marshes, a wide-spread bed of pebbles, gravel, and sand was accumulated by the waves dashing rudely over the surface of the rising continent; and these pebble-beds make the *Millstone grit* that marks the commencement of the Carboniferous period in a large part of eastern North America, especially along the Appalachian region, and also in Europe.

(4.) *Coal-plant Areas in the Carboniferous Period.*—Then began the *epoch of the Coal measures.*

The positions of the great coal areas of North America (see map, p. 69) are the positions, beyond question, of the great marshes and shallow fresh-water lakes of the period. But it is probable that the number of these marshes was less than that of the coal areas. The Appalachian, Illinois, Missouri, Arkansas, and Texas fields may have made one vast *Interior continental* marsh-region, and those of Rhode Island, Nova Scotia, and New Brunswick an *Eastern border* marsh-region. There is some reason, however, for believing that a low area of dry land (or not marshy land), extending from the region of Cincinnati into Tennessee, divided the Interior marsh, or at least its northern portion.

The Michigan marsh-region appears also to have had its dry margins, instead of coalescing with the Illinois or Ohio areas.

It is not to be inferred that the marshes alone were covered with verdure. The vegetation probably spread over all the dry land, though making thick deposits of vegetable remains only where there were marshes under dense jungle growth and shallow lakes with their floating islands.

(5.) *Alternations of Condition, Changes of Level.*—It has been remarked that the many alternations of the coal-beds with sandstones, shales, conglomerates, and limestones (p. 117), are evidence of as many alternations of level during the era. After the great marshes had been long under verdure, the ocean began again to encroach upon them, and finally swept over the whole surface, destroying the land and fresh-water life of the area,—that is, the land and fresh-water Plants, Mollusks, Insects, and Reptiles,—but distributing at the same time the new life of the salt waters. Then, after another long period of various oscillations in the water-level, in which sedimentary beds in many alternations were formed, the continent again rose to aerial life, and the marshes and shallow lakes were luxuriant anew with the Carboniferous vegetation. Thus the sea prevailed at intervals—intervals of long duration—through the era even of the Coal measures; for the associated sedimentary beds, as has been stated, are at least fifty times as thick as the coal beds.

These oscillations continued until 3000 to 4000 feet of strata were formed in Pennsylvania, and over 14,000 in Nova Scotia.

The Carboniferous period was, therefore, ever varying in its geography. A map of its condition when the great coal beds were accumulating would have its eastern coast-line not far inside of the present, and in the region of Nova Scotia and New England even *outside* of the present. The southern coast-line would pass through central Carolina, Georgia, and Alabama, and northern Mississippi, then, west of the Mississippi, around Arkansas and the bordering counties of Texas; thence it would stretch northward, bounding a sea covering a large part of the Rocky Mountain region, for the Coal period was in that part of the continent mainly a time of limestone-making. But in a map representing it during the succeeding times of submergence, the coast-line would run through south middle New England, then near the southern boundary of New York State, then northwestward around Michigan, then southward again to northern Illinois, and then westward and northwestward to the Upper Missouri region, or the Rocky Mountain sea. Through these conditions, as the extremes, the continent passed several times in the course of the Carboniferous period.

(6.) *Condition in the Permian Period.*—Finally, in the Permian period, the Appalachian region, and the Interior region east of a north-and-south line running through Missouri, appear to have been mainly above the ocean; for the Permian beds are mostly confined to the meridian of Kansas and the remoter West.

GENERAL OBSERVATIONS ON THE PALEOZOIC.

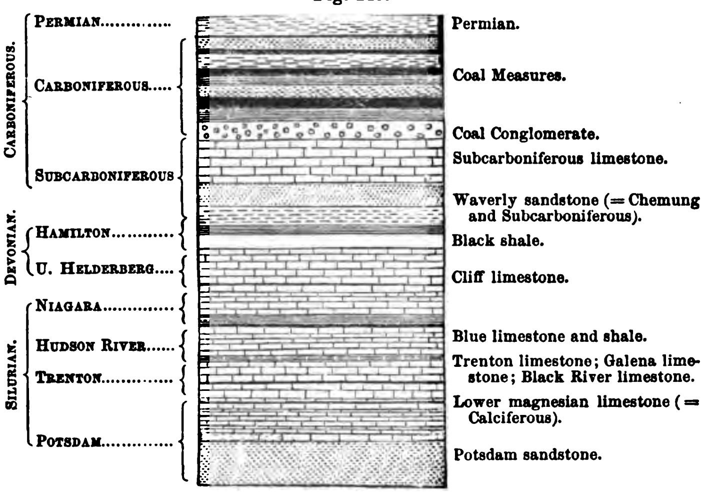
1. **Rocks.**—(1.) *Maximum thickness.*—The maximum thickness of the rocks of the Silurian age in North America is 22,000 feet; of the Devonian, about 14,000 feet; and of the Carboniferous age, under 15,000 feet.

(2.) *Diversities of the different Continental regions as to kinds of rocks.*—The Paleozoic rocks of the Appalachian region are mainly sandstones, shales, and conglomerates; only about *one-fourth* in thickness of the whole consists of limestone. The rocks of the Interior continental are mostly limestone, full two-thirds being of this nature.

The difference of these two regions, in this particular, will be appreciated on comparing the following general section of the strata of the Interior with the section, on page 66, of the rocks of New York,—New York State lying on the inner borders of the Appalachian region. The Lower Silurian beds in the Mississippi basin, as the section shows, consist mainly of limestones; so also the Upper Silurian, Devonian, and Subcarboniferous formations; and the Carboniferous of the region contains more limestone than that of the East. In the Devonian of the Interior, a *black shale*, one or two hundred feet thick, is the only representative of the Hamilton group; and a few hundred feet of sandstone —part of the so-called *Waverly sandstone*—corresponds to the Chemung group, or Uppermost Devonian.

In the Eastern border region, about the Gulf of St. Lawrence, there is a great predominance of limestones in the

Fig. 249.



Section of the Paleozoic rocks in the Mississippi basin.

formations. They prove the existence in that region of an Atlantic border basin similar in some respects to the basin of the Interior,—the two being separated by the northern part of the Appalachian region.

(3.) *Diversities of the Appalachian and Interior Continental regions as to the thickness of the rocks.*—In the *Appalachian* region the maximum thickness of the Paleozoic rocks is about 50,000 feet. But this thickness is not observed at any one locality, it being obtained by adding together the greatest thicknesses of the several formations wherever observed. The greatest actual thickness at any one place in Pennsylvania is about 36,000 feet, or between 6½ and 7 miles.

In the central portions of the *Interior continental* region, the thickness varies from 3500 feet (and still less on the northern border) to 6000 feet; and it is, therefore, from *one-sixth* to *one-tenth* that in the Appalachian region.

(4.) *Origin of the deposits.*—The *fragmental* rocks, as those of sand, clay, mud, pebbles (or the sandstones, shales, earthy sandstones and conglomerates), were made from the wear of pre-existing rocks under the action of water. The water was mainly that of the ocean, and the power was that of the waves and currents. The material acted upon was subjected to wave-action, and must have been at or near the surface. The material of the coarser rocks may have been accumulating where the waves were dashing against a beach or an exposed sand-reef, or else where currents were in rapid movement over the bottom; for accumulations of pebbles and coarse sand are now made under these circumstances. The material of the earthy sandstones may have been the mud or earthy sands forming the bottom of shallow seas. The fine clayey or earthy deposits must have been made in sheltered bays or interior seas, in which the waves were light, and, therefore, fitted to produce by their gentle attrition the finest of mud; or else in the deeper off-shore waters, where the finer detritus of the shores is liable to be borne by the currents.

Accumulations of any degree of thickness may be made in *shallow* waters, provided the region is undergoing very slow subsidence; for in this way the depth of the waters may be kept sufficient to allow of constantly increasing depositions. Thus, by a slow subsidence of 1000 feet, deposits 1000 feet thick may be produced, and the depth of water at no time exceed 20 feet. The occurrence of ripple-marks, mud-cracks, or rain-drop impressions in many beds of most of the formations, proves that the layers so marked were successively near the surface, and, therefore, that there must have been a gradual sinking of the bottom as the beds were formed.

The *limestones* of the Paleozoic were probably made, in every case, out of organic remains, as Shells, Corals, Crinoids, etc., and perhaps in some cases (as that of the Lower Magnesian limestones of the Interior) out of minute Rhizopods, which are known to have formed, to a large extent, the chalk-beds of Europe. Shells, Corals, and Crinoids must be ground up by the waves to form fine-grained rocks; while the shells of Rhizopods are so minute as to be already fine grains, and may become compact rocks by simple consolidation.

The *hornstone* in the limestones, as remarked on page 109, may be wholly of organic origin.

2. **Time-Ratios.**—Judging from the maximum thickness of the rocks of the several Paleozoic ages in North America, and allowing that *five* feet of fragmental rocks may accumulate in the time required for one foot of limestone, the relative lengths of the Silurian, Devonian, and Carboniferous ages were not far from 3 : 1 : 1, and the Lower Silurian era was four times as long as the Upper.

Thus time moved on slowly in the earth's first beginnings. The condition of the earth in an age of Mollusks, when only Invertebrates and Sea-weeds were living,—when all life was the life of the waters, and nothing existed above the ocean's level,—was very inferior to that of the Carboniferous, when the continents had their forests, the waters their fishes, and the marshes their reptiles. Yet the length of the time through which the earth was groping under the first-mentioned condition was at least three times that under the last; and the earlier Lower Silurian era was four times as long as the Upper Silurian. Such was the divine system in the progress of creation. Such is time in the view of the infinite Creator.

3. **Geography.**—(1.) *Close of Azoic time.*—The map on page 73 shows approximately the outline of the dry land of North America at the close of Azoic time. The only mountains were Azoic mountains, the principal of which were the Laurentian of Canada and the Adirondack of northern New York. We cannot judge of the height of these mountains then from what we now see, after all the ages of Geology have passed over them, for the elements and running water have never ceased action since the time of their uplift, and the amount of loss by degradation must have been very great.

(2.) *General Progress through Paleozoic time.*—The increase of *dry land* during the Paleozoic has been shown (pp. 99, 115) to have taken place mainly along the borders of the Azoic, so that the old nucleus has been on the gradual increase. This increase is well marked from north to south across New York. At the close of the Lower Silurian, the shore-line was not far from the present position of the Mohawk, showing but a slight extension of the dry land in the course of this very long era; when the Upper Silurian ended, the shore-line extended along 15 or 20 miles south of the Mohawk. When the Devonian ended and the Carboniferous age was about opening, the coast-line was just north of the Pennsylvania boundary. Thus, the dry part of the continent was on the slow increase.

The progress southward was at an equal rate in Wisconsin, where there is an isolated Azoic region like that of northern New York. In the intermediate district of Michigan, the coast made a deep northern bend through the Silurian and Devonian. In the Carboniferous the same great Michigan bay existed during the intervals of submergence;

but it was changed to a Michigan marsh or fresh-water lake, filled with Coal-measure vegetation during the intervening portions of the Carboniferous period; and at the same times, as explained on page 140, the continent east of the western meridian of Missouri had nearly its present extent, though not its mountains or its rivers.

(3.) *Regions of rock-making, and their differences.*—The submerged part of the continent was the scene of nearly all the rock-making; and this work probably went on over its whole wide extent.

The rocks, as partially explained on page 144, varied in kind with the depth and with the exposure to the open sea.

This *Interior continental* region, which was for the most of the time a great interior oceanic sea, afforded the conditions fitted for the growth of corals and crinoids and other clear-water species, and hence for the making of limestone reefs out of their remains; for limestones are the principal rocks of the interior. Yet there were oscillations in the level; for there are abrupt transitions in the limestones, and some sandstones and shales alternate with them. But these oscillations were not great, the whole thickness of the rocks, as stated on page 144, being small.

The *Appalachian* region, on the contrary, presented the conditions required for fragmental deposits. It was apparently a region of immense sand-reefs and mud-flats, with bays, estuaries, and extensive submerged plateaus or off-shore soundings, such as might have existed in the face of the ocean. Here, too, the change of level was very great; for within this region occur the 6½ to 7 miles of Paleozoic formations (p. 144), and even 9 miles, reckoning the maximum amount of all the deposits. This vast thickness indicates that while there were various upward and downward movements over this Appalachian region through Paleozoic time, the downward movements exceeded the upward even by the amount just stated. These movements, moreover, were in progress from the Potsdam period onward; the formations of nearly every period in the series exceed 8 to 10 times the thickness they have over the Interior region.

(4.) *Mountains of Paleozoic origin.*—The mountains in eastern North America, made in the course of the Paleozoic ages, were few. Those of the region south of Lake Superior about Keweenaw Point, and to the west, probably rose during the latter part of the Potsdam period. The Green Mountain region became dry land after the Lower Silurian (p. 91); but there is no reason to believe that it was very much raised; for the eastern half of Vermont was beneath the ocean, and became covered by coral reefs and other formations during the Devonian age. The Devonian beds of the vicinity of Gaspé may have been raised into ridges before the Carboniferous age began. But the larger part of the continental area was still without mountains. The Rocky chain had only some ridges as islands in the seas, and the Appalachians were yet to be made.

(5.) *Rivers—Lakes.*—The depression between the New York and the Canada Azoic, dating from the Azoic age, was the first indication of a future St. Lawrence channel. It continued to be an arm of the sea, or deep bay, through the Silurian, and underwent a great amount of subsidence as it received its thick Canadian formations. After the Silurian age, marine strata ceased to form, indicating thereby that the sea had retired; and fresh waters, derived from the Azoic heights of Canada and New York, probably began their flow along its upper portion, and emptied into the St. Lawrence Gulf of the time not far below Montreal.

The raising of New York State out of water at the close of the Devonian suggests that from that time the Hudson valley was a stream of fresh water. The valley itself, and its continuation north as the Champlain valley, date from the close of the Lower Silurian.

The Mississippi and its tributaries, east and west, were not in existence in the Paleozoic ages. In the intervals of Carboniferous verdure, when the continent was emerged, the Ohio and Mississippi basin were regions of great marshes, lakes, and bayous, and not of great rivers; for rivers could not exist without a head of high land to supply water and give it a flow.

Lake Superior was a district of vast rock-deposits and extensive igneous eruptions in the Potsdam period, or near the close of that period, as well as in the closing Azoic; and the thick accumulations show that deep subsidences were then in progress there, as also in the region of the St. Lawrence; so that we may infer that the basin of this great lake was already in process of formation before the Lower Silurian closed. The extent and position of the great Michigan bay through the Silurian and Devonian ages and much of the Carboniferous, as mentioned on pp. 99, 142, show that Lakes Erie, Huron, and Michigan were then within the limits of this bay. Whether deeper or not than other portions of the bay, is not known.

Thus, Geology studies the Geography of the Paleozoic ages, and traces North America through its successive stages of growth.

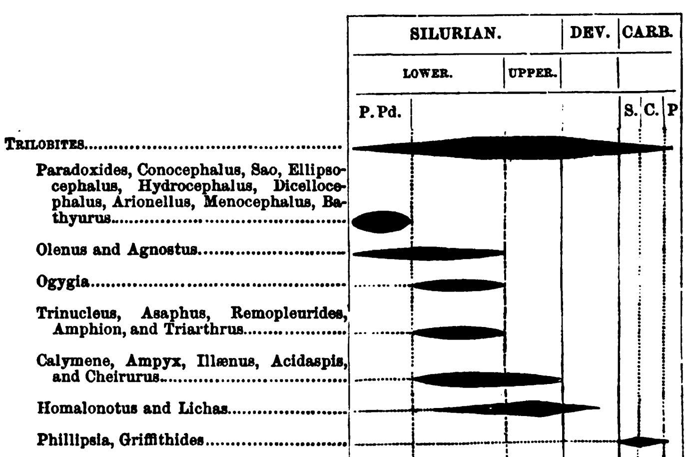
4. **Climate.**—No evidence has been found through the Paleozoic records of any marked difference of temperature between the zones. In the Carboniferous age the Arctic seas had their Corals and Brachiopods, and the Arctic lands their forests and marshes under dense foliage, no less than those of America and Europe. The facts on this subject are stated on p. 138.

5. **Life.**—(1.) *Appearance and disappearance of species.*—With each new period in the progressing ages, new living species were introduced; and, as each period ended, the old more or less completely passed away, or were exterminated. There were also partial destructions attending the many minor changes in the rock-formations, as in the transition

from the formation of a bed of shale to that of sandstone or of limestone, or the reverse; and some new species made their appearance with each new stratum. Thus, destructions and creations took place at intervals through the whole course of the ages.

(2.) *The exterminations indicated not in harmony with any development-theory.*—This extermination of the life of a period or epoch, according to the evidence gathered from the rocks, cut short not only species, but *genera, families*, and *tribes;* and yet these same genera and tribes were often begun again by other species, and so continued on. Had the system of creation been dependent on the development of *species from species*, this would have been impossible. The system could not have withstood the disasters it had to encounter.

(3.) *Beginning and ending of genera, families, and higher groups.*—The following table of the tribe of Trilobites illustrates the general character of the progress which took place in this and other groups:—



The vertical columns correspond to the Lower and Upper Silurian, the Devonian, and the Carboniferous. The left-hand column under Lower Silurian corresponds to the first, or Primordial period; and the three columns under the Carboniferous, to the Subcarboniferous, Carboniferous, and Permian periods of the age. The widths of the columns are made to represent, as nearly as possible, the relative lengths of the eras. Opposite TRILOBITES, the black area shows that the tribe began with the beginning of the Paleozoic and continued nearly to its end. Next there are the names of nine genera which existed only in the Primordial Period, each having then one or many species, but none afterwards. Then there are two genera, *Olenus* and *Agnostus*, which continued from the Primordial through the Lower Silurian. Then, others confined to the rest of the Lower Silurian; others that passed into the Upper Silurian, then to become extinct; others that continued into the Devonian; and two genera confined to the Carboniferous. These genera included more than 500 species. Of the Carboniferous genera the last species had been exterminated before the close of the age.

In a similar manner the genera and families of Brachiopods began at different periods or epochs, and continued on for a while, to become, in general, extinct. Many genera ended in the course of the Paleozoic and at its close; only a few continued into later periods.

(4.) *Long-lived genera.*—Two Lower Silurian genera of Brachiopods continue from the Primordial period, not only through Paleozoic and Mesozoic time, but onward to the present age, having species in existing seas. They are *Lingula* and *Discina.* It will be noted that these genera survived through the long ages of the past, not by the uninterrupted existence of any of their species, but by the perpetuating of the type of form and structure characterizing the genera in a succession of distinct species.

(5.) *Unity of plan in nature.*—These long generic lines, stretching on with such uniformity from the very beginnings of life on the globe, are proofs of the unity of plan through the system of creation.

(6.) *Permanency of types, notwithstanding the influence of external causes.*—As this uniformity has remained in spite of the vast physical changes the globe has undergone since life began, it is evidence of the strongest kind as to the little power which external causes have towards producing changes in types.

The facts bear abundant testimony to a Creating Power above nature, carrying forward a preordained plan. Moreover, there is evidence even in the Paleozoic records—their coal-beds, iron-ores, and the system of life in progress of expansion—that this plan involved the future existence of a being that should have knowledge to use the coal and iron, and power to read the records and discern in God's marvellous works His wisdom and beneficence.

(7.) *General characteristics of Paleozoic life.*—Both plants and animals were marine through, or till near the close of, the Silurian age. In the Devonian age there were terrestrial plants and animals, and a still greater diversity of life over the land in the Carboniferous. The characteristics of the life of the Silurian age are mentioned on page 103; of that of the Devonian, on page 115; and of that of the Carboniferous, on page 125.

(8.) *Special Paleozoic peculiarities of the life.*—The following facts show in what respects the life of the Paleozoic ages was peculiarly *ancient*:—

a. Not only are the species all extinct, but almost every genus. But 15 or 16 of the genera which existed in the course of the Paleozoic have *living* species; *and all these are Molluscan.*

b. Among Radiates, the Polyps were largely of the tribe of *Cyathophylloid* corals, which is exclusively ancient, or

Paleozoic, not a species having lived after the close of the Carboniferous age. The Echinoderms were mostly *Crinoids*, and these were in great profusion. Crinoids were far less abundant, and of different genera, in the Mesozoic; and now, very few exist.

c. Among Mollusks, *Brachiopods* were exceedingly abundant: their fossil shells far outweigh those of all other Mollusks. They were much less numerous than other Mollusks in the Mesozoic; and at the present time the group is nearly extinct. The Cephalopods were represented very largely by *Orthocerata*, but few species of which existed in the early Mesozoic, and none afterwards.

d. Among Articulates, *Trilobites* were the most common Crustaceans,—a group *exclusively* Paleozoic.

e. Among Vertebrates, the Devonian Fishes were either *Ganoids* or *Selachians*, and the Ganoids were the *heterocercal* species. Of heterocercal Ganoids, but few species lived in the first period of the Mesozoic; and the whole group of Ganoids is now nearly extinct. Of the Selachians, a large proportion were *Cestracionts*,—a tribe common in the Mesozoic, but now nearly extinct.

f. Among terrestrial Plants, there were *Lepidodendra*, *Sigillariæ*, *Calamites* in great profusion, making, with Conifers and Ferns, the forests and jungles of the Carboniferous and later Devonian: no *Lepidodendron* or *Sigillaria* existed afterwards, and the *Calamites* ended in the Mesozoic.

Thus, the Paleozoic or *ancient* aspect of the animal life was produced through the great predominance of *Brachiopods*, *Crinoids*, *Cyathophylloid Corals*, *Orthocerata*, *Trilobites*, and *heterocercal Ganoids;* and that of the plants over the land, through the *Lepidodendra*, *Sigillariæ*, and *Calamites*, along with *Ferns* and *Conifers*. In addition to this should be mentioned the absence of *Angiosperms* and *Palms* among Plants; the absence of *Teliost Fishes*, *Birds*, and *Mammals*, among Vertebrates; and of *nearly all modern tribes of genera* among Radiates, Mollusks, and Articulates.

g. Mesozoic and Modern types begun in Paleozoic time.—The principal *Mesozoic* type which began in the Paleozoic was the Reptilian. But besides Reptiles there were the first of the Decapod Crustaceans; the first of Oysters; and the first of the great tribe of Ammonites, the *Goniatites* being of this tribe.

The type of Insects, or terrestrial Articulates, belongs eminently to modern time; for it has now its fullest display. It dates from the existence of terrestrial plants in the Devonian.

Thus, while the Paleozoic ages were progressing, and the types peculiar to them were passing through their time of greatest expansion in numbers and perfection of structure, there were other types introduced which should have their culmination in a future age. The Reptiles and Goniatites of the later Paleozoic were precursors of the Age of Reptiles which followed, in accordance with the principle exemplified in all history, that the characteristics of an age commence to appear in the age preceding.

DISTURBANCES CLOSING PALEOZOIC TIME.

1. *General quiet of the Paleozoic Ages.*—The long ages of the Paleozoic passed with but few and comparatively small disturbances of the strata of eastern North America. There were some early permanent uplifts in the Lake Superior region, and along the course of the Green Mountains, and some later in the district of Gaspé near St. Lawrence Bay; there was, through the ages, a gradual increase on the north in the amount of dry land; there were, through parts of all the periods, slow oscillations in progress, varying the water-level and favoring the increasing thickness of the rocks, and their successive variations as to kind and extent. But these changes were probably caused by exceedingly slow movements of the earth's crust,—probably less than a foot

a century. There may have been occasional quakings of the earth,—even exceeding the heaviest of modern earthquakes. There may have been at times sudden raisings or sinkings of the continental crust. But, while there were some uplifts, as above mentioned, there is nothing in the condition of the strata indicating a general or extensive upturning.

2. *The Appalachian the region of greatest change of level through the Paleozoic Ages.*—The region of greatest movement during these ages was the *Appalachian.* For it has been shown that the oscillations which there took place resulted in subsidences of one or more thousand feet with nearly every period of the Paleozoic. The oscillations ceased in the Green Mountain portion after the close of the Lower Silurian era, but not until the subsidence there had reached at least 10,000 feet; and in Pennsylvania and Virginia they continued through a large part of the Carboniferous Age, until the sinking amounted to 35,000 or 38,000 feet. But all this sinking was probably quiet in its progress, as is proved by the regularity in the series of strata.

The thickness of the coal-beds indicates that the coal-plant marshes were long undisturbed, and therefore that long periods passed without appreciable movement.

3. *Approach of the epoch of Appalachian revolution.*—The era of comparative quiet alluded to came gradually to a close as the Carboniferous age was terminating, and an epoch of upturning, metamorphism, and mountain-making began. There are mountains to testify to this both in Europe and America.

In eastern North America the disturbances affected the Appalachian region and Atlantic border from Newfoundland to Alabama, and the Appalachian mountains are a part of the result. The epoch is hence appropriately styled the epoch of the Appalachian revolution. The region in eastern America of the deepest Paleozoic subsidence and of the thickest accumulation of Paleozoic rocks was now the region of the profoundest disturbances and the greatest uplifts.

4. *Effects of the disturbances.*—The following are among the effects of the disturbances along the Appalachian region and Atlantic border:—

(1.) Strata were upraised and flexed into great folds, many of the folds a score or more of miles in span.

(2.) Deep fissures of the earth's crust were opened, and faults innumerable were produced, some of them of 10,000 to 20,000 feet.

(3.) Rocks were consolidated; and, over a large part of New England and the more southern Atlantic border, sandstones and shales were crystallized into granite, gneiss, mica and argillaceous schist and other related rocks, and limestone into architectural and statuary marble.

(4.) At the same time, the crystallized and consolidated rocks had their fractures filled with mineral material making veins,—some of them being filled with rock alone, making veins of quartz, granite, etc.; others with rock and associated metallic minerals, making metallic veins, as of lead-ore, copper-ore, gold; others were made containing gems, as topaz, beryl, and the like. Diamonds, also, are among the results of the metamorphism.

(5.) Bituminous coal was turned into anthracite in Pennsylvania and Rhode Island.

(6.) In the end, the Appalachian mountains were made.

5. *Evidence of the flexures, uplifts, and metamorphism.*—The evidence that the rocks of the Appalachian region and Atlantic border were flexed, uplifted, faulted, and otherwise changed from their original condition, is as follows:—

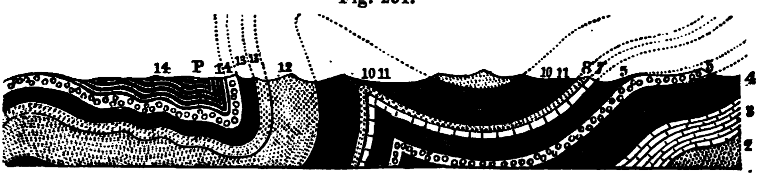
The Coal measures and other Paleozoic strata, though originally spread out in horizontal beds, are now in an uplifted and flexed or folded condition; and they are so involved together in one system of flexures and uplifts that the whole must have been the result of one system of movements. Figures 250–253 illustrate this.

Fig. 250.

Section of the Coal measures, near Nesquehoning, Pa.

Fig. 250 shows the condition of the Anthracite coal-beds of Mauch Chunk in Pennsylvania. Some of the upturned

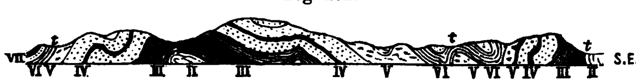
Fig. 251.



Section on the Schuylkill, Pa.; P. Pottsville on the Coal measures; 2, Calciferous formation; 3, Trenton; 4, Hudson River; 5, Oneida and Niagara; 7, Lower Helderberg; 8, 10, 11, Devonian; 12, 13, Subcarboniferous; 14, Carboniferous, or Coal measures.

beds, as is seen, stand nearly vertical. Fig. 251 is from another locality near Pottsville in the same State. The coal

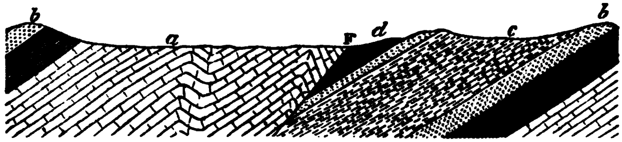
Fig. 252.



Section from the Great North to the Little North Mountain through Bore Springs, Va.; *t, t*, position of thermal springs; II, Calciferous formation; III, Trenton; IV, Hudson River; V, Oneida; VI, Clinton and Lower Helderberg; VII, Oriskany Sandstone and Cauda-Galli Grit.

beds are the upper ones below 14; the rest are the beds of the Upper and Lower Silurian (2 to 7); the Devonian (8, 10, 11), and Subcarboniferous (12, 13). Fig. 252 was taken from the vicinity of Bore Springs in Virginia, and includes Silurian and Devonian beds: it shows well the folded character of the rocks. Fig. 253 represents one of the great faults in southern Virginia (between Walker's Mountain and

Fig. 253.



Section of the Paleozoic formations of the Appalachians in southern Virginia, between Walker's Mt. and the Peak Hills (near Peak Creek Valley): F, fault; *a*, Lower Silurian limestone; *b*, Upper Silurian; *c*, Devonian; *d*, Subcarboniferous, with coal beds.

Peak Hills); the break is at F, and along it the rocks on the left were shoved up along the sloping fracture until a Lower Silurian limestone (*a*) was on a level with the Subcarboniferous formation (*d*), a fault of at least 10,000 feet. Such examples are in great numbers throughout the Appalachians. In many of the transverse valleys the curves may be traced for scores of miles.

As shown in the above sections (figs. 250–253), the folds, instead of remaining in regular rounded ridges with even synclinal valleys between, such as the flexing of the strata might make, have been to a great extent worn away, or modelled into new ridges and valleys, by the action of waters during subsequent time; and often what was the top of a fold is now the bottom of a valley, because the folds would be most broken where most abruptly bent,—that is, along the axes of flexure,—and hence would be most liable in this part to be cut away or gorged out by any denuding causes. The figures on page 41 illustrate still further the condition of folded strata before and after denudation. Some of the Appalachian folds were probably 20,000 feet in height above the present level of the ocean, or would have had this height if they had remained unbroken, while in fact the loftiest summits now are less than 7000 feet, and few exceed 5000 feet.

Over New England there are similar flexures. Those of the Rhode Island coal formation are very abrupt, and full of faults, the coal-beds being much broken and displaced. Through eastern Vermont, and in Massachusetts for some distance west of the Connecticut River, there are Devonian strata in the same condition; although the rocks are in general crystalline, Devonian fossils have been found at Bernardston in Massachusetts, and on Lake Memphremagog. At the latter place there was once a coral-reef (p. 105). It is inferred from the facts that even the granites, gneiss, and slates of the White Mountains, and the gneiss of Haddam, Connecticut, were originally Devonian sedimentary strata, and that all New England is made of folded and metamorphosed Paleozoic rocks.

Similar facts might be cited from Nova Scotia on the north and Alabama on the south, proving that a region 1000 miles in length along the Atlantic border, from Newfoundland to the Gulf States, participated in the grand movement.

6. *General truths with regard to the results.*—The following are some of the general truths connected with the uplifts and metamorphism :—

(1.) The courses of the flexures and of the outcrops or strike, and those of the great faults, are approximately northeast, or parallel to the Atlantic border. There is a bend eastward in Pennsylvania corresponding with the eastward bend of the southern coast of New England, and then a change to the northward in New England.

(2.) The folds have their steepest slope *towards the northwest*, or away from the ocean. If fig. 41 (page 42) represent one of the folds, the left would be the ocean side, or that to the southeast, and the right the landward side, or that to the northwest.

(3.) The flexures are most numerous and most crowded on that side of the Appalachian region which is *towards the ocean*, and diminish westward. There is seldom, however, a gradual dying out westward, the region of disturbance being often bounded on the west by one or more of the great fractures and faults, as in eastern Tennessee and along the valley of the Hudson.

(4.) The wearing away of the summits of the folds when crowded together produces a series of *southeast* dips, as illustrated in figures 41, 42 (p. 42). Such southeast dips, not looking as if they were ever due to folds, characterize the rocks of much of New England and the eastern part of the Appalachian region.

(5.) The metamorphism of the strata is more extensive and complete to the eastward (or towards the ocean) than to the westward.

(6.) The change of bituminous coal to anthracite, by an expulsion of the bitumen, was most complete where the disturbances were greatest,—that is, in the Eastern coal regions. The anthracite region of Pennsylvania (see map, p. 118) owes its broken character partly to the uplifts and partly to denudation. To the westward, the coal is first semibituminous, and then, as at Pittsburg, true bituminous. In Rhode Island, where the associated rocks are partly true metamorphic or crystalline rocks and the disturbances are very great, the coal is an excessively hard anthracite, and in some places is altered to graphite (an effect which may be produced in ordinary coal by the heat of a furnace). The bed of graphite near Worcester in Massachusetts is supposed to be an altered coal seam.

7. *Conclusions.*—These facts lead to the following conclusions:—

(1.) The movement producing these vast results was due to lateral pressure, the folding having taken place just as it might in paper or cloth under a lateral or pushing movement.

(2.) The pressure was exerted at right angles to the courses of the folds, as is the case when paper is folded in the manner mentioned.

(3.) The pressure was exerted *from* the ocean side of the

Appalachians; for the results in foldings and metamorphism are most marked towards the ocean.

(4.) The force was vast in amount.

(5.) The force was slow in action and long continued,—and not abrupt or paroxysmal as when a wave or series of waves is thrown up by an earthquake shock on the surface of an ocean. For the strata were not reduced by it to a state of chaos, but retain their stratification, and show comparatively little confusion, even in the regions of greatest disturbance and alteration.

(6.) The action of the force was connected with the emission of heat. For without some heat above the ordinary temperature, it is not possible to account for the consolidation and crystallization of the rocks.

(7.) The history of the Appalachian Mountains stretches through all the geological ages from the Azoic onward. Through the Silurian, Devonian, and Carboniferous ages, the formations were accumulating to a great thickness, while slow oscillations of level were in progress. When the Carboniferous age was closing, these oscillations, which had resulted in a subsidence of several miles, began to culminate in profounder movements, producing flexures of the earth's crust, uplifts, faults, consolidation, and metamorphism, and ending in the elevation of the mountains. And finally, during these upliftings, moving waters commenced the work of denudation,—the chiselling of the heights, which has continued to the present time.

8. *Disturbances on other continents.*—The amount of cotemporaneous mountain-making over the globe at this epoch has not yet been clearly made out. Enough is known to render it probable that the Ural Mountains, with their veins of gold and platinum, were made at the same time with the Appalachians, and that uplifts and metamorphism also occurred in other parts of Europe, and in Great Britain. Murchison states that the close of the Carboniferous

period was specially marked by disturbances and uplifts; that it was then "that the coal strata and their antecedent formations were very generally broken up, and thrown, by grand upheavals, into separate basins, which were fractured by numberless powerful dislocations."

The epoch of the Appalachian revolution was, then, a grand epoch for the world. The complete extermination of life which took place at the time was probably a consequence of these great physical changes progressing over the earth's surface. The Appalachian Mountains stand up as boldly between Paleozoic and Mesozoic time as between the ocean and the Interior Continental basin.

III. MESOZOIC TIME.

1. **Ages.**—Mesozoic or medieval time, in Geological history, comprises but one age,—the REPTILIAN. In the course of it, the class of Reptiles passed its culminations;—that is, its species increased in numbers, size, and diversity of forms, until they vastly exceeded in each of these respects the Reptiles of either earlier or later time.

2. **Area of progress in rock-making.**—The area of rock-making in North America, during Mesozoic time, was somewhat different from what it was in Paleozoic. Then, nearly the whole continent, outside of the northern Azoic, was receiving its successive formations; and the three great regions were the *Eastern border*, the *Appalachian*, and the *Interior Continental.* By the close of the Paleozoic era, the Appalachian region and the *Interior* east of the Mississippi, excepting its southern portion, had become part of the dry land of the continent, as is shown by the absence of marine strata of later date. The great areas of progress were consequently changed, and became—(1) the *Atlantic border*, (2) the *Gulf border*, and (3) the *Western Interior*, or region

west of the Mississippi. In other words, the continent, from the Mesozoic onward, until the close of the Tertiary period in the Cenozoic, was receiving its new marine formations only along its borders and over the part of the Interior region which covers the present site of the slopes of the Rocky Mountains.

These three regions are continuous with one another, the Atlantic connecting with the Gulf border region on the south, and the Gulf border region passing northwestward into the Western Interior or Rocky Mountain region.

In Europe no analogous change can be distinguished; for the continent was, from the first, an archipelago; and it continued to bear this geographical character, though with an increasing prevalence of dry land, until the Cenozoic era had half passed. Western England then stood as three or four islands above the sea (the area marked as covered by Paleozoic rocks on the map, p. 120), and the area of future rock-making was mainly confined to the intervals between these islands and to the submerged area on the east and southeast; and it is probable that this area and a portion of northeastern France were part of a large German-Ocean basin.

REPTILIAN AGE.

Periods.—The Reptilian Age includes three periods:—

1. Triassic:—named from the Latin *tria, three,* in allusion to the fact that the rocks of the period in Germany consist of three separate groups of strata. This is a local subdivision, not characterizing the rocks in Britain or in most other parts of Europe.

2. Jurassic:—named from the Jura Mountains, situated on the eastern border of France, between France and Switzerland, where rocks of the period occur.

3. Cretaceous:—named from the Latin *creta, chalk,* the chalk beds of Britain and Europe being included in the Cretaceous formation.

1. TRIASSIC AND JURASSIC PERIODS.

1. Rocks: kinds and distribution.

The American rocks of the Triassic period have not yet been separated from those of the Jurassic, except in a few points west of the Mississippi.

In the *Atlantic border* region, these Mesozoic rocks occupy narrow ranges of country parallel with the Appalachian chain, following its varying courses. One of these ranges occupies the valley of the Connecticut between northern Massachusetts and New Haven on Long Island Sound, and runs parallel with the Green Mountains: it has a length of about 110 miles. Another—the longest of them—commences at the north extremity of the Palisades, on the west bank of the Hudson River, and stretches southwestward through New Jersey, Pennsylvania (here bending much to the westward, like the Appalachians of the State, as shown in the map on page 118), and reaching far into the State of Virginia. Another stretches—almost in the line of the last—through North Carolina. There is another along western Nova Scotia. These, and some other smaller areas, are indicated on the map on p. 69 by an oblique lining in which the lines run from the right above to the left below.

The rocks are mainly sandstones and conglomerates, but include some considerable beds of shale, and in some places a bed of impure limestone. The sandstones are generally red or brownish-red. The *freestone* of Portland, near Middletown in Connecticut, and of Newark in New Jersey, are from the formation. The pebbles and sand of the beds were derived from the granites, gneiss, schists, etc. that were crystallized in the epoch of the Appalachian revolution; and in some of the coarser kinds large stones of granite and mica schist may be taken from the layers. The strata overlie directly, but unconformably, these metamorphic rocks. Near Richmond in Virginia and in North Carolina there are valuable coal-beds in this formation. The coal is bituminous.

The several ranges of this sandstone formation are remarkable for the great number of trap ridges and trap dikes intersecting them (p. 30). Mount Holyoke in Massachusetts, East and West Rocks near New Haven in Connecticut, and the Palisades on the Hudson, are a few examples of these trap ridges. Trap is an igneous rock, one that was ejected in a melted state from a deep-seated source of fire, through fissures made by fracturing the earth's crust. The dikes and ridges are exceedingly numerous, and have the same general course with the sandstone ranges. They are so associated with the sandstone formation that there appears to be some connection in origin between the water-made and the fire-made rocks. The proofs that the trap came up through the fissures in a melted state are abundant; for the wall-rock of the fissures is often baked so as to be very hard, and is sometimes filled with crystallizations, as of epidote or tourmaline, evidently due to the heat.

West of the Mississippi—that is, in the Western Interior region—there is a sandstone formation containing much gypsum (and hence called the *Gypsiferous formation*), which is barren of fossils, except an occasional fragment or trunk of fossil wood and some Reptilian remains. It probably spreads widely over the Rocky Mountain region beneath the later beds. It comes out to view on the western borders of Kansas, and also in the Colorado region beyond the summit of the Rocky Mountains. Owing to the absence of marine fossils, it has not been determined whether the formation is Triassic, lower Jurassic, or both united.

In the vicinity of the Black Hills in the region of the upper Missouri, there are some beds of impure limestone containing marine fossils which are true Jurassic. (Meek and Hayden). These beds overlie the gypsiferous formation just mentioned.

In *Europe* the Triassic rocks of eastern France and Germany, east and west of the Rhine, consist of a Shell limestone (called in German *Muschelkalk*) between an underlying thick reddish sandstone (*Bunter Sandstein*) and overlying strata of reddish and mottled marlites and sandstone (*Keuper* of the Germans). In *England* (see No. 6 on map, p. 120), the rock is a reddish sandstone and marlite; it is mostly confined to a region running north-northwest just east of the Paleozoic areas mentioned on page 163, and to an extension of this region westward to Liverpool bay (or over the interval between the two main areas) and up the west coast.

This formation, in Europe, contains in many places beds of salt, and is hence often called the *Saliferous group*. At Northwich in Cheshire, in England, there are two beds of rock-salt, 90 to 100 feet thick; and in Europe there are similar beds at Vic and Dieuze in France, and at Wurtemberg in Germany.

The Jurassic rocks of Britain and Europe are divided into three principal groups:—

1. The *Liassic* (No. 7 *a* on map of England, p. 120), consisting of grayish compact limestone strata, called *Lias*.

2. The *Oolitic* (No. 7 *b* on map, p. 120), consisting mostly of whitish and grayish limestones, part of them oolitic (p. 25). One stratum, near the middle of the series, is a coral-reef limestone, much like the reef-rock of existing coral seas, though wholly different in species of coral. Near the top of the series there are some local beds of *fresh-water* or *terrestrial* origin, in what is called the Purbeck group, and one on the island of Portland is named, significantly, the *Portland dirt-bed.* The Solenhofen lithographic limestone is a very fine-grained rock (thereby fit for lithography), of the age of the Middle Oolite, occurring in Pappenheim in Bavaria.

3. The *Wealden* (No. 8 on the map of England): a series

of beds of estuary and fresh-water origin, mostly clay and sand, but partly of limestone. They occur in southeastern England. They are named *Wealden* from the region where first studied, called the *Weald*, covering parts of Kent, Surrey, and Sussex.

2. Life.

1. *Plants.*

The vegetation of the Triassic and Jurassic periods included numerous kinds of *Ferns*, both large and small, *Calamites*, and *Conifers*, and so far resembled that of the Carboniferous age. But there were no forests or jungles of Lepidodendra and Sigillariæ. Instead of these Carboniferous types, a new group of trees and shrubs existed,—that of the *Cycads*. This group was eminently characteristic of the Mesozoic world: it has now but few living species, and among the genera, *Cycas* and *Zamia* are those whose names are best known. The plants have the aspect of palms; and there was, therefore, in the Mesozoic forests a mingling of palm-like foliage with that of Conifers (spruces, cypress, and the like). But the Cycads are not true Palms. They are *Gymnosperms*, like the *Conifers* both in the structure of the wood and in the fruit. The resemblance to Palms is mainly in the cluster of great leaves at the summit, and in the appearance of the exterior of the trunk. Fig. 254 represents the leaf of a modern species reduced to one-twentieth the actual length; and fig. 255 the trunk of

Figs. 254, 255.

Fig. 254, Leaf of a living Zamia ($\times \frac{1}{20}$); 255, Stump of the Cycad, Mantellia (Cycadeoidea) megalophylla ($\times \frac{1}{30}$).

a fossil species from the Portland dirt-bed, where they are common. The trunks of some Cycads have a height of 15 or 20 feet. Although the form of the leaf is palm-like, the leaflets do not split lengthwise with facility, like those of Palms. In one important respect these Cycads resemble the Ferns,—that is, in the unfolding of the young leaf,—the leaf being at first rolled up into a coil, and gra-

Figs. 256–260.

Fig. 256, Podozamites lanceolatus; 257, Pterophyllum graminioides; 258, Clathropteris rectiusculus; 259, Pecopteris Stuttgartensis; 260, Cyclopteris linnæifolia.

dually unrolling as it expands. The Cycads thus combine peculiarities of three orders of plants,—Ferns, Palms, and Conifers,—and are examples, therefore, of what are called *comprehensive* types.

Fossil plants are common in the coal regions of Richmond, Virginia, and in North Carolina, and occur also in other localities. The following figures represent some of the species. Figs. 256, 257 are parts of the leaves of two species of Cycads, from North Carolina. Figs. 258 to 260 represent a few of the ferns: fig. 258, a *Clathropteris*, from East Hampton, Mass.; fig. 259, a *Pecopteris*, from Richmond, Va., and the Trias of Europe; fig. 260, a *Cyclopteris*, from Richmond, Va. Large cones of firs have also been found. Several of the American plants are identical in species with those of the European Triassic, and a few nearer to Jurassic forms.

2. *Animals.*

A. AMERICAN.

The American beds of the *Atlantic border* region are remarkable for the *absence of true marine* life: all the species appear to be either those of brackish water, or of fresh water or the land.

1. *Radiates and Mollusks.*—Radiates are unknown. There are very few *Mollusks* of any kind, and these are *Conchifers.*

2. *Articulates.*—The shells of *Ostracoid Crustaceans* are common in Pennsylvania, Virginia, and North Carolina, but have not yet been found in New England. Fig. 261 represents one of the little shells of these bivalve species, called an *Estheria*. It was long supposed to be Molluscan. The *Estheriæ* are brackish-water species.

Fig. 261.

Estheria ovata.

A few remains of *Insects* have been found, and, what is more remarkable, the tracks of several species. These tracks were left on the soft mud probably by the larves of the Insects, for certain kinds pass their larval state in the water. Fig. 262 represents one of these larves found in shale at Turner's Falls in Massachusetts; it resembles, according to Dr. Le Conte, the larve of a modern *Ephemera*. Figs. 263, 264 are the tracks of Insects. Prof. Hitchcock has named nearly 30 species of tracks of Insects and Crustaceans.

Vertebrates.—There are evidences of the existence of *Fishes*, *Reptiles*, *Birds*, and *Mammals*. The last two types here make their first appearance, and thus the sub-kingdom of Vertebrates is finally represented in all its classes.

The Fishes found in the American rocks are all *Ganoids*, although *Selachian* remains are common in Europe. Fig. 265 represents one of the species, reduced one-half.

Figs. 262–264.

ARTICULATES.—Fig. 262, Palephemera mediæva ($\times \frac{3}{8}$); 263, 264, Tracks of Insects.

Fig. 265.

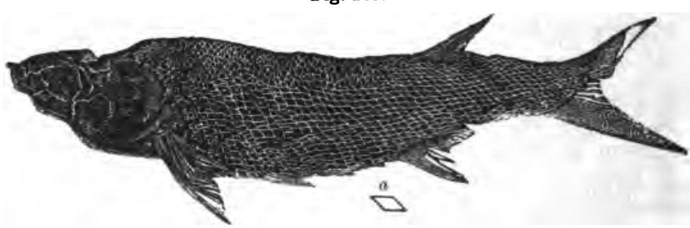
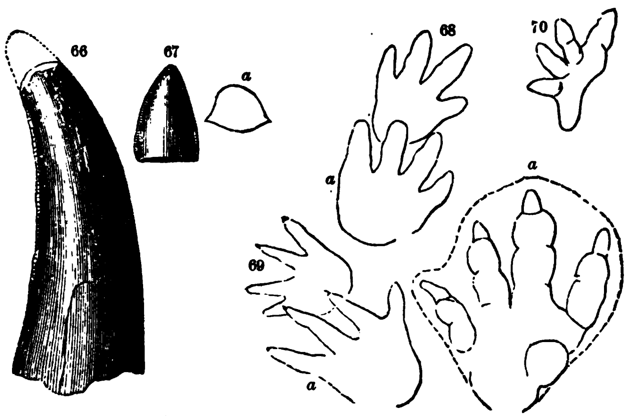


Fig. 265, GANOID, Catopterus gracilis ($\times \frac{1}{2}$); *a*, Scale of same, natural size.

The Reptiles of the era are known to us partly from their fossil bones and partly from their footprints. The footprints indicate a wonderful variety as to form and size. Bones have been found especially in Pennsylvania, North Carolina, and Nova Scotia. Fig. 266 represents a tooth, half the natural size, of a Nova Scotia species (*Bathygnathus borealis* of Leidy); and fig. 267, a tooth of another, from North Carolina, *Palæosaurus Carolinensis* Emmons. Several kinds occur at Phœnixville, Pa., where there is literally a *bone-bed.*

Figs. 268–270 represent the tracks of three species of Reptiles from the Connecticut valley beds; 268–270 are

Figs. 266–270.



REPTILES.—Fig. 266, Bathygnathus borealis (× ½); 267, Palæosaurus Carolinensis; 267 *a*, section of same; 268, 268 *a*, fore and hind feet of Anisopus Deweyanus (× ½); 269, 269 *a*, id. of A. gracilis (× ⅜); 270, 270 *a*, id. of Otozoum Moodii (× 1/18).

the impressions made by the fore-foot in each, and 268 *a*, 269 *a*, 270 *a*, of the hind-foot. Fig. 270 is reduced to *one-eighteenth* the natural size, the actual length of the track being 20 inches. The animal is called *Otozoum Moodii* by Hitchcock: it appears to have walked like a biped, bringing its fore-feet to the ground only occasionally, impressions of these feet being seldom found. The animal had a stride of 3 feet, and must have been of formidable dimensions. One slab, 30 feet long, in the collection of Amherst College (Massachusetts) contains 11 tracks of this huge animal. Some of the Reptiles made three-toed tracks, closely like those of birds; and this fact has led some to question whether all may not be Reptilian.

The tracks regarded as those of birds are also very numerous. The largest of them is nearly 2 feet long (fig. 271), far exceeding that of an Ostrich, and even surpassing that which the giant *Moa* of New Zealand might have made (p.

Figs. 271, 272.

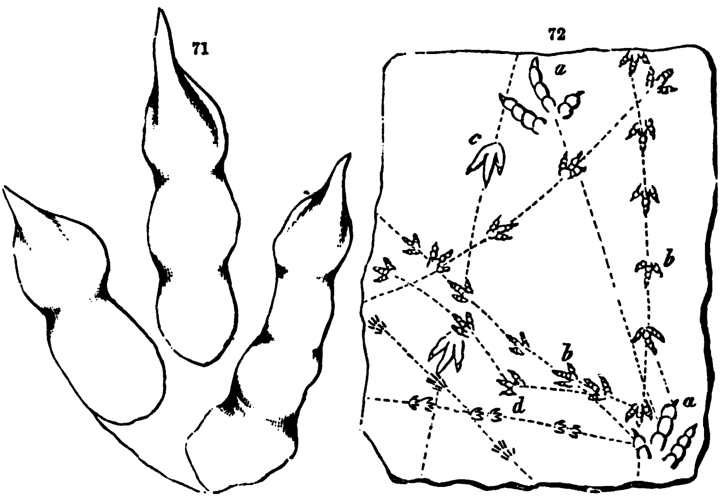


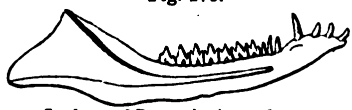
Fig. 271, Track of Brontozoum giganteum (× 1/6); 272, Slab of sandstone with tracks of Birds and Reptiles (× 1/30).

241). Fig. 272 represents, on a small scale, a slab from the Connecticut River sandstone covered with tracks of birds and reptiles, as figured by Hitchcock. The two tracks lettered *a* are added, of larger proportional size than the others, to show more distinctly the form.

The only relic of a *Mammal* yet discovered in the American rocks is a *jawbone* (fig. 273). It is from North Carolina, and is named *Dromatherium sylvestre* by Emmons. It belongs to the order of Marsupials, the same which contains the modern *Opossum*.

The facts prove that the land-population of Mesozoic America included *Insects*, *Reptiles*, *Birds*, and *Marsupial Mammals*, and that the forests that covered the hills were mainly composed of *Conifers* and *Cycads*.

Fig. 273.

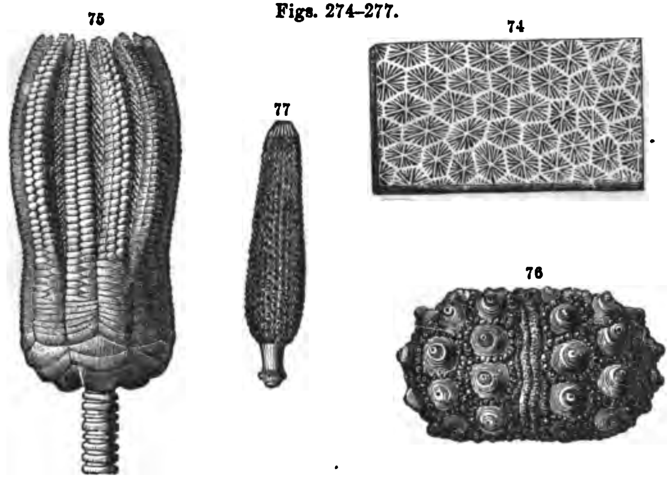


Jawbone of Dromatherium sylvestre.

B. Foreign.

The European and British rocks of these periods, especially of the Jurassic, abound in marine fossils, and afford a

Figs. 274–277.

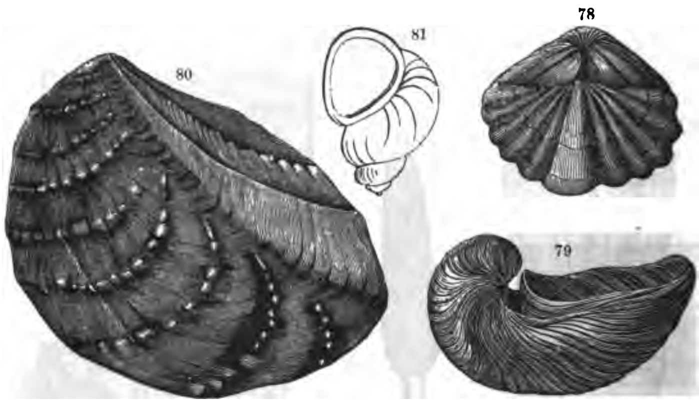


Radiates.—Fig. 274, the Coral, Prionastræa oblonga; 275, the Crinoid, Encrinus liliiformis; 276, Cidaris Blumenbachii; 277, Spine of same.

knowledge of the Mesozoic life of the ocean which we fail to get from the American records. The remains of terrestrial life are also of great interest, and, like the American, they attest the existence of *Birds* and *Mammals* in the course of the era.

1. *Radiates.*—Polyp-corals are common in some Jurassic strata: they are related to the modern tribe of corals, and not to the ancient: none of the Paleozoic types existed. Fig. 274 is one of the oolitic species. Crinoids are of many kinds, yet their number, as compared with other fossils, is far less than in the preceding ages; and they are accompanied by various new forms of *Star-fishes* and *Echini* (p. 57). Fig. 275 represents one of the Triassic Crinoids, the *Lily-Encrinite*, or *Encrinus liliiformis;* fig. 276, an *Echinus*, from

Figs. 278–281.



MOLLUSKS.—Fig. 278, Spirifer Walcotti; 279, Gryphæa arcuata; 280, Trigonia clavellata; 281, Vivipara (Paludina) Fluviorum.

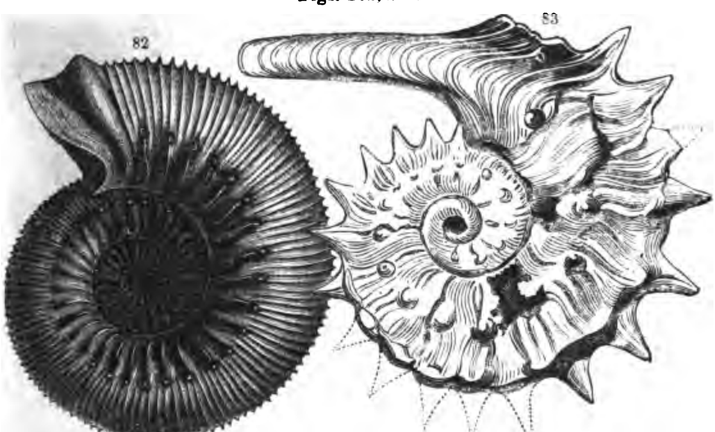
the Oolite, stripped of its spines, and fig. 277, one of the spines separate.

2. *Mollusks.*—*Brachiopods* are few compared with the Paleozoic. The last species of the Paleozoic families of the *Spirifers* and *Leptænas* lived in the earlier part of the Jurassic period. Fig. 278 represents one of these last of the Spiri-

fer group. *Conchifers* and *Gasteropods* abound in species, and under various new, and many of them modern, genera. The genus *Gryphæa* (fig. 279 representing a Liassic species) is common in the Lias and later Mesozoic rocks: it is an oyster with the beak incurved. *Trigonia* (fig. 280) is a characteristic genus of the Mesozoic. The name alludes to the triangular form of the shell: the species figured is from the Oolite. Fig. 281 represents a fresh-water snail-shell, a very abundant fossil in fresh-water limestone of the Wealden, closely resembling many modern species.

But the most remarkable and characteristic of all Mesozoic Mollusks were the *Cephalopods*. This order passed its maximum as to number and size in the Mesozoic, and hundreds of species existed. The last of the Paleozoic type of *Ortho-*

Figs. 282, 283.

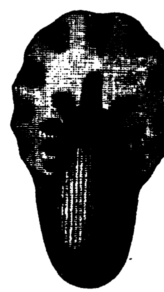


MOLLUSKS.—Fig. 282, Ammonites Humphreysianus; 283, A. Jason.

cerata and *Goniatites* lived in the Triassic Period. In the same period began the genus *Ammonites*, the most common of the Mesozoic genera, and in the earliest Jurassic the family of *Belemnites*, another peculiarly Mesozoic type.

The *Ammonites* had *external* shells like the *Nautili* (p. 55). Two Oolitic species are represented in figs. 282, 283. One of them (fig. 283) has the side of the aperture very much prolonged; but the margin of the shell, whether prolonged or not, is seldom well preserved. The partitions (or septa) within the shells of *Ammonites* are bent back in many folds (and much plaited within each fold) at their junction with the shell, so as to make deep plaited pockets. The front view of the outer plate, with the entrances to its side-pockets, are seen in fig. 284. The fleshy mantle of the animal descended into these pockets, and thus the animal was aided in holding firmly to its shell. The siphuncle in the *Ammonites* is dorsal. The Paleozoic *Goniatites* were of the Ammonite family, but the pockets were much more simple, the flexures of the margins of the partitions being without plications.

Fig. 284.



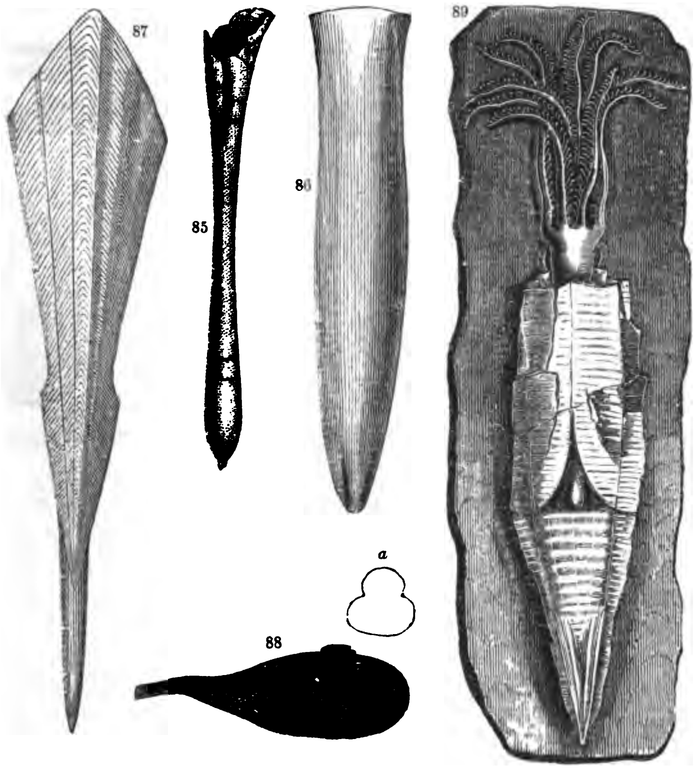
Ammonites tornatus.

The fossil *Belemnite* is the *internal* bone of a kind of *Cephalopod*, analogous to the pen or internal bone (or osselet) of a *Sepia*, or *Cuttle-fish* (see fig. 289). It is a thick, heavy fossil, of the forms in figs. 285, 286, having a conical cavity at the upper end. The fossils are more or less broken at this extremity; when entire, the margin of the aperture is elongated into a thin edge, and sometimes, on one side, into a thin plate of the form in fig. 287. The animal had an ink-bag like the modern Sepia; and ink from these ancient Cephalopods has been used in sketching their fossil remains. Fig. 288 represents one of the ink-bags of the Jurassic Cephalopods. Fig. 289 is another related Cephalopod, showing something of the form of the animal, and also the ink-bag in place.

3. *Articulates.*—The Articulates included various shrimps, or craw-fishes (fig. 290, a Triassic species), Crabs, and Te-

tradecapod (or 14-footed) Crustaceans (fig. 291, representing a species something like the modern *Sow-bug*), but *no*

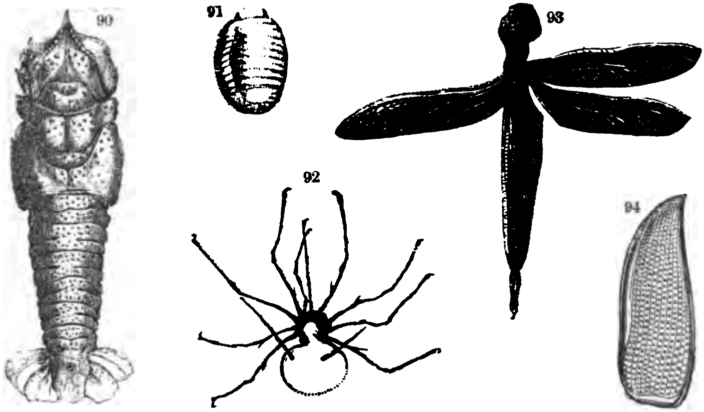
Figs. 285–289.



Mollusks.—Fig. 285, Belemnites pistilliformis; 286, B. paxillosus; 286 *a*, Outline of section of same, near extremity; 287, View, reduced, of the complete osselet of a Belemnite; 288, Fossil Ink-bags of a Cephalopod; 289, Acanthoteuthis antiquus.

Trilobites; also the first known of true Spiders (fig. 292), and species of many of the orders of Insects. Fig. 293 is a *Libellula*, or *Dragon-fly*, of the Jurassic period, from Solenhofen; and fig. 294, the wing-case of a beetle, from the Stonesfield Oolite.

Figs. 290–294.



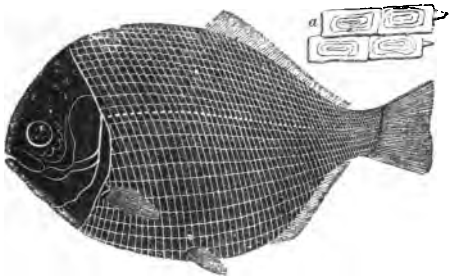
ARTICULATES.—Fig. 290, Pemphix Sueurii; 291, Archæoniscus Brodiei; 292, Palpipes priscus; 293, Libellula; 294, Wing-case of a Buprestis.

3. *Vertebrates.*—The *Fishes* were all either *Ganoids* or *Selachians.* In the Triassic beds occurred the *last* species of the *heterocercal* Ganoids, and the *first* of the *homocercal,* along with some, like fig. 265, p. 170, of intermediate character,—that is, having the tail-fin vertebrated through *half* its length. Fig. 295 represents one of the homocercal Ganoids of the Lias. Among the *Sharks* (or Selachians) the *Cestraciont* tribe, the most ancient, characterized by a pavement of grinding teeth (p. 52), still continued, and was very numerously represented. There were also in the Jurassic beds the first of the sharp-edged Shark-teeth, or those of the tribe of Sharks that inhabits modern waters.

Reptiles were the dominant race in the Reptilian world, and among them were Amphibians, the division most common in the Carboniferous age, and also great numbers of true Reptiles. They included species for each of the elements,—the water, the earth, and the air.

In the Triassic the Amphibian division (p. 50) appears

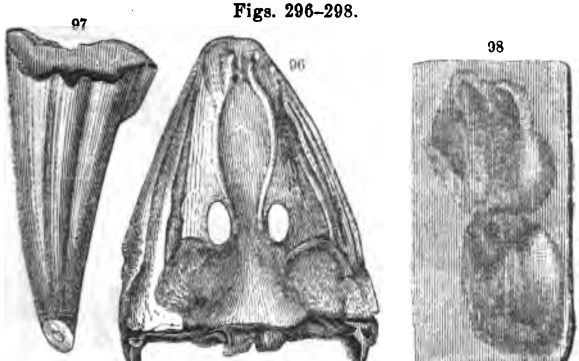
Fig. 295.



VERTEBRATE.—Fig. 295, Restored figure of Æchmodus (Tetragonolepis) (× 1/6); 295 *a*, Scales of same.

to have reached its maximum. One of the frog-like *Labyrinthodonts* had a skull of the form shown in fig. 296, whose

Figs. 296–298.

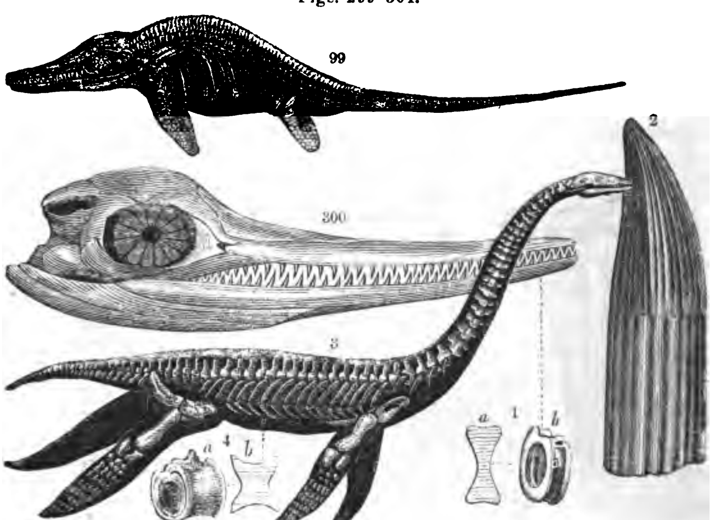


VERTEBRATES.—Fig. 296, Skull of Mastodonsaurus Jægeri (× 1/12); 297, Tooth of same (× 1/2); 298, Footprints of Cheriotherium (× 1/12).

length was 3 to 4 feet; its mouth was set around with teeth 3 inches long (fig. 297), and the body was covered with scales. The specimen figured was found in Saxony. It is probable that some of the American Reptilian species whose tracks are so common in the Connecticut valley were of this type. Fig. 298 is a reduced view of hand-like tracks, from the same locality as the above, supposed to have been made by an animal of the same species. The frogs of the present day are feeble and diminutive compared with the Triassic Amphibians.

Swimming Reptiles, or Saurians,—called *Enaliosaurs* because of their living in the sea (from the Greek *enalios*, *marine*, and *sauros*, *lizard*),—probably existed in the Carboniferous age (p. 135): they became numerous and of great size in the Mesozoic. They had paddles like Whales, and thus

Figs. 299–304.



VERTEBRATES.—Fig. 299, Ichthyosaurus communis (×$\frac{1}{100}$); 300, Head of same (×$\frac{1}{30}$); 301 *a*, 301 *b*, View and section of vertebra of same (×$\frac{1}{3}$); 302, Tooth of same, natural size; 303, Plesiosaurus dolichodeirus (×$\frac{1}{30}$); 304 *a*, 304 *b*, View and section of vertebra of same.

were well fitted for marine life. The most common kinds were the *Ichthyosaurs* and *Plesiosaurs*.

The *Ichthyosaurs* (fig. 299) had a short neck, a long and large head, enormous eyes, and thin, fish-like, or doubly-concave, vertebræ. The name is from the Greek *ichthus*, *fish*, and *saur*. Fig. 300 represents the head of an *Ichthyosaur*, *one-thirtieth* the natural length, showing the large size of the eye and the great number of the teeth. Fig. 301 *b* is one of the vertebræ, reduced, and fig. 301 *a*, a transverse section of the same, exhibiting the fact that both surfaces are deeply concave, nearly as in fishes; fig. 302 is one of the teeth, natural size. Some of the Ichthyosaurs were 30 feet long.

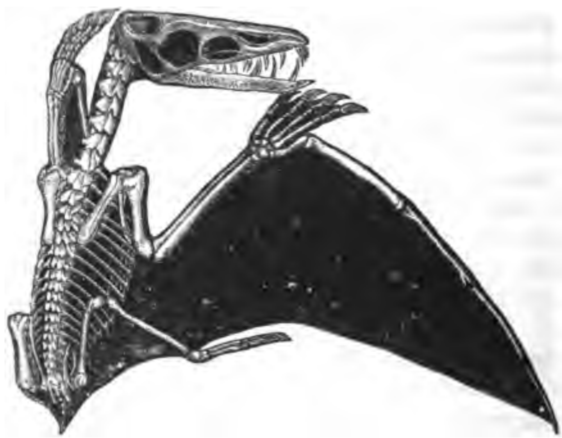
The *Plesiosaurs* (named from the Greek *plesios*, *near*, and *saur*, because not quite like a Saurian), one of which is represented very much reduced in fig. 303, had a long snake-like neck, a comparatively short body, and a small head. Fig. 304 *a* represents one of the vertebræ, and 304 *b*, a section of the same; it is doubly-concave, but less so, and much thicker, than in the *Ichthyosaurs*. Some species of Plesiosaur were 25 to 30 feet long. Another related Reptile, called a *Pliosaur*, was 30 to 40 feet long. Remains of more than 50 species of *Enaliosaurs* have been found in the Jurassic rocks.

Besides these swimming Saurians, there were numerous species of Lacertians (*Lizards*) and *Crocodilians* 10 to 50 feet long, and *Dinosaurs*, the bulkiest and highest in rank of the Saurians, 25 to 60 feet long.

To the group of Dinosaurs belongs the *Iguanodon*, of the Wealden beds, first made known by Dr. Mantell, whose body was 28 to 30 feet long, and which stood high above the ground quadruped-like, the femur, or thigh-bone, alone being nearly 3 feet long. Its habits are supposed to have been like those of a *Hippopotamus*,—the animal grazing on the plants and shrubs of the marshes, estuaries, or streams in or about which it lived. It had teeth like the modern *Iguana* (and hence the name, from *Iguana*, and the Greek *odous*, *tooth*), but it had proportionally a much shorter tail. The *Megalosaur* was another of the gigantic Dinosaurs of the later part of the Jurassic period; it was a terrestrial carnivorous Saurian, about 30 feet in length.

The Reptiles adapted for the air—that is, for flying—are designated *Pterosaurs*, from the Greek *pteron*, a *wing*, and *saur*. The most common genus is called *Pterodactylus*. The general form of a *Pterodactyl* is shown in fig. 305. The bone of one of the fingers is greatly elongated, for the purpose of

Fig. 305.



VERTEBRATE.—Pterodactylus crassirostris (× ¼).

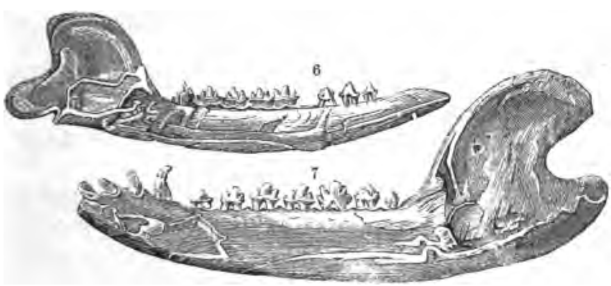
supporting an expanded membrane, so as to make it serve (like an analogous arrangement in bats) for flying. The name *Pterodactyl* is from the Greek *pteron*, *wing*, and *daktulos*, *finger*. The *Pterodactyls* were mostly small, and probably had the habits of bats; the largest had a spread of wing of about 10 feet. Unlike birds, they had a mouth full of teeth, and no feathers. As Bats are flying Mammals, so the *Pterosaurs* are simply flying Reptiles, and have no resemblance to birds in structure, except that their bones are hollow.

Besides the kinds of Reptiles already mentioned, there were *Turtles* in the Jurassic period; but, according to present knowledge, the world contained *no Snakes.*

Coprolites (or fossil excrements) of both Reptiles and Fishes are common in the bone-beds. When cut and polished they have a degree of beauty sufficient to have made them formerly an object of some value in jewelry.

Remains of *Birds* have been found in the quarries of Solenhofen (p. 166). They have revealed the fact that some at least of the Mesozoic species (and of America, beyond question, as well as Europe) were *reptilian* in some of their characters. The skeleton found shows that the Birds had long reptile-like tails consisting of many vertebræ, and finger-like claws on the fore limb or wing, like those of the *Pterodactyl* and *Bat*, fitting them evidently for clinging. But, while thus reptilian in some points of structure, they were actually *Birds*, being feathered animals, and having the expanse of the wing made, not by an expanded membrane as in the Pterodactyl, but by long quill-feathers.

Figs. 306, 307.



VERTEBRATES.—Fig. 306, Amphitherium Broderipii (× 2); 307, Phascolotherium Bucklandi (× 2).

The tail-quills were arranged in a row either side of the long tail. The feet were precisely like those of birds.

Remains of *Mammals* occur in the Upper Trias (or base of the Lias) of Germany, in the Lower Oolite deposit at Stonesfield, England, and in the Portland "dirt-bed" of the Upper Oolite (p. 166). Nearly 20 species have been made out, 14 of them from relics in the Portland "dirt-bed." The larger part are *Marsupials;* a few are pronounced to be non-marsupial Mammals of the order of *Insectivores.* Figs. 306, 307 represent the jaws of two species from Stonesfield, magnified twice the natural size.

As Marsupials are semi-oviparous Mammals, and therefore are *intermediate* between ordinary Mammals and the inferior and oviparous Vertebrates (p. 50), it follows that both the *Birds* and *Mammals* of the Mesozoic were *in part*, at least, *comprehensive* or *intermediate* types, and partook of reptilian features in the Reptilian age.

3. General Observations.

1. **American Geography.**—The Mesozoic sandstones and shales of the Atlantic border region are sedimentary beds; consequently, the long narrow ranges of country in which they were formed were occupied at the time more or less completely by water.

The absence of true marine fossils has been remarked upon as proving that this water was either brackish or fresh; and hence the areas were estuaries or deep bays running far into the land.

There was probably an abundance of marine life in the ocean, if we may judge from its diversity on the other side of the Atlantic; but the seacoast of the era must have been outside of the present one, so that any true marine or sea-coast deposits that were made are now submerged. The present sea-border is shallow for a distance of 80 miles from the New Jersey coast, the depth of water at this distance out being but 600 feet.

As all the depressions or valleys occupied by the estuaries are parallel with the Appalachians (p. 164), and since the era of the formations was that next following the origin of these mountains, the depressions must have been made at the time the Appalachian foldings were in progress. In fact, they are some of the great valleys or depressions left in the course of the upliftings.

The level of the several sandstone areas above the ocean proves that the land at the time was not far from its present elevation, and therefore that the Appalachians had probably nearly their present height.

The deposits contain foot-prints, ripple-marks, rain-drop impressions, and other evidences, on many of the layers, that they were formed partly in shallow waters, and partly as sand-flats, or emerging marshes and shores, over which reptiles and birds might have walked or waded. If, then, they are several thousands of feet thick, there must have been a progressing subsidence of the valley-depressions—that is, a sinking must have been going on. It is hence apparent that the oscillations of level that characterized the epoch of the Appalachian revolution were still in progress. Two effects of this subsidence occurred:—(1) The sandstone beds were more or less faulted and tilted, those of the Connecticut valley receiving a dip to the eastward, those of New Jersey and Pennsylvania to the northwestward. (2) In the sinking of the valley-depression, an increasing strain was produced in the earth's crystalline crust beneath, which finally became so great that the crust broke, fissures opened, and liquid rock came up. The dikes and ridges of trap are this liquid rock solidified by cooling. The existence of the dikes, and their parallelism to the general course of the valley-depressions, prove—(1) the fact of the fractures; (2) their resulting from the same cause which produced the sinking; and (3) the fact of the igneous ejections. The earth's crust along the Connecticut valley was thus a scene of igneous operations for a length over 100 miles, and through a vast number of opened fissures. The Palisades of the Hudson date from the same period,—probably the middle of the Jurassic period.

The *Western Interior*, or *Rocky Mountain* region, had been mostly submerged during the Carboniferous age, as shown by the fact that limestones were forming there in the Coal Measure period, and fossiliferous sandstones in the Permian. The Gypsiferous sandstone of the Mesozoic proves, by its nature, its gypsum, and its rare fossils, that, by some change, this great region had become mostly an *interior* shallow salt sea, shut off to a great extent from the ocean. Such a sea would have been made too fresh for marine life in the rainy season, and probably too salt for any life in the hot season. Hence, as in the Great Salt Lake of Utah, life would have been absent. The salt waters by evaporation would have furnished gypsum to the beds, as happens now sometimes from sea-water. It follows, then, from the beds of the Atlantic border as well as those of the Western Interior, that the continent during the era of these Mesozoic beds was to a less extent submerged than in the greater part of the Paleozoic ages and the following portion of the Mesozoic. The fossiliferous Jurassic beds mentioned on page 165 show that before the Jurassic period had closed, the sea had again free access over it; and the later Cretaceous formations prove that in the Cretaceous period also this marine condition prevailed.

2. **Foreign Geography.**—The nature of the Triassic beds of Britain and Europe show that there were large *shallow interior seas* also on the eastern side of the Atlantic. The salt-deposits in the beds, the paucity of fossils in the most of the strata, and the prevalence of marlites, indicate the same conditions as existed in New York during the formation of the Saliferous beds of the Upper Silurian (see page 95), and somewhat similar to those in which the Rocky

Mountain Gypsiferous formation originated. The limestone that intervened along the Rhine, between the two formations of sandstone and marlites, shows an interval of more open sea; yet the impurity of the limestone suggests that the ocean had not full sweep over the region.

The beds of the Jurassic period are almost all of them evidence, both from their constitution and their abundant marine life, that the free ocean again had sway over large portions of the Continental area. Its limits, however, became more contracted as the period passed, and towards its close fresh-water and terrestrial beds were forming in some places that had earlier in the period been under salt water.

3. **Climate.**—The Jurassic coral reefs of Britain indicate that England then lay within the sub-tropical oceanic zone. This zone now has the parallel of 27° to 28° as, in general, its outer limit (lying mostly between 20° and 27°); and, consequently, its Jurassic limit, if including England, reached twice as far towards the pole as now. It is possible, however, that the line ran along the British Channel, and that the Gulf Stream of the era carried the sub-tropical temperature northeastward through the British seas, as it now does to Bermuda, in latitude 34°.

The following are other facts of similar import. In Arctic America, species of shells allied to those of Europe and tropical South America occur in latitudes 60° to 77° 16′; and one species of *Belemnite* and one of *Ammonite* are said to be *identical* with species occurring in these two remote and now widely different regions. If not absolutely identical, the evidence from them as to oceanic temperature is nearly the same. Moreover, on Exmouth Island, in 77° 16′ N., remains of an *Ichthyosaur* have been found, and in 76° 22′ N., on Bathurst Island, bones of other large Jurassic Reptiles (*Teleosaurs*). It is probable, therefore, that a warm-temperate oceanic zone covered the Arctic to the parallel of 78°, if not beyond. No large living reptiles exist outside of the warm-temperate zone.

2. CRETACEOUS PERIOD.

General characteristics.—The Cretaceous, while the closing period of Mesozoic time, was also, in some respects, a transition period between the Mesozoic and Cenozoic. During its progress, as is explained beyond, occurred the decline, and, at its close, the extinction, of a large number of the tribes of the medieval world, while, at the same time, there appeared in its course other tribes eminently characteristic of the modern world. Among these modernizing features, the most prominent arose from the introduction of *Palms* and *Angiosperms* among plants, and *Teliosts* among fishes.

The Palms and Angiosperms include nearly all the fruit-trees of the world, and constitute far the larger part of modern forests. The Conifers and Cycads, wherever they now occur near groves of Angiosperms, exhibit the contrast between the medieval foliage and that of the present age. The Teliosts (p. 50) embrace nearly all modern fishes excepting those of the order of Sharks, or Selachians. Their appearance was as great a change for the waters as the new tribes of plants for the land. These tribes of plants and fishes were only begun in the Cretaceous; their full exhibition belongs to Cenozoic time and the Age of Man.

1. Rocks: kinds and distribution.

In North America, the Cretaceous formation borders the continent on the Atlantic side, south of New York, and along the north and west sides of the Gulf of Mexico; besides, it spreads from Texas, northward, over the slopes of the Rocky Mountains, being now at a height in some places of 6000 to 7000 feet above the sea. Its beds are exposed to view in New Jersey and in some portions of the more southern Atlantic States, though mostly covered by the Tertiary. They are largely displayed through Alabama and Mississippi, and cover a great area west of the Mississippi. (See map, p. 69).

In England the formation occupies a region just east of the Jurassic, stretching from Dorset on the British Channel eastward, and also northeastward to Norfolk on the German Ocean, and continuing near the borders of this ocean, still farther north, beyond Flamborough Head: it is numbered 9 on the map, p. 120. Cretaceous rocks occur also in northern and southern France, and many other parts of Europe.

Among the rocks there are the following kinds:—the soft variety of limestone called *Chalk;* hard limestones; ordinary hard sandstones; shales and conglomerates like those of other ages; but, more common than these, soft sand-beds, clay-beds, and shell-beds, so imperfectly consolidated that they may be turned up with a pick.

Many of the sand-beds or sandstones have a dark-green color, and are called *green-sand.* The green color is owing to the presence of dark-green grains which occur mixed with more or less of common sand. They are a hydrous silicate of iron and potash. This *green-sand* is often used for fertilizing land, and when so used it is called *marl.*

Chalk-beds are the source of *flint.* The flint is distributed through the chalk in layers, these layers being made up of nodules of flint, or masses of irregular forms. Although often of rounded forms, they are not water-worn stones of foreign origin, but were formed in place, like the *hornstone* in the Corniferous limestone of New York (p. 105).

Chalk constitutes a large proportion of the Cretaceous formation in England and some parts of Europe, but is not known in the American Cretaceous. The succession of beds in England is as follows:—(1) The *Lower Cretaceous,* consisting largely of the Green-sand and other arenaceous beds, called collectively the *Lower Green-sand;* (2) the

Middle Cretaceous, containing the *Upper Green-sand* and some other beds; (3) the Upper Cretaceous, comprising the *Chalk-beds*, the lower part of which is without flints.

The Cretaceous beds in North America are supposed to correspond to the Middle and Upper of the European Cretaceous. They consist of layers of Green-sand, thick sand-beds of other kinds, clays, shell-beds, and, in some places in the States bordering on the Mexican Gulf (especially in Texas), limestone. The thickness of the formation in New Jersey is 400 to 500 feet; in Alabama, 500 to 600 feet; in Texas, about 800, nearly all of it compact limestone; in the region of the Upper Missouri, 2000 to 2500 feet.

2. Life.

1. *Plants.*

The first of Angiosperms and of Palms, as already stated, date from the Cretaceous period. Leaves of a few American species of the former are represented in figs. 308–311; fig. 309, from a species of *Sassafras;* fig. 310, a *Liriodendron;* and fig. 311, a *Willow;* and with these occur leaves of *Oak*, *Dogwood*, *Beech*, *Poplar*, &c.

Besides these highest of plants, there were also Conifers, Ferns, and Sea-weeds, as in former time, with some Cycads still. The microscopic Algæ called *Diatoms* (p. 61), which make siliceous shells, and others called *Desmids* (p. 61), which consist of one or a few simple green cellules, were very abundant. Both occur fossil in flint; and a species of the latter is very similar to one from the Devonian hornstone figured on page 109 (fig. 180). The Diatoms are believed to have contributed part of the silica of which the flint is formed.

2. *Animals.*

1. *Protozoans.*—The simplest of animals, *Rhizopods*, of the group of Protozoans (p. 59), were of great geological importance in the Cretaceous period; for the Chalk is supposed

to be made mostly from their minute calcareous shells. The powdered chalk is often found to contain large numbers of

Figs. 308–311.

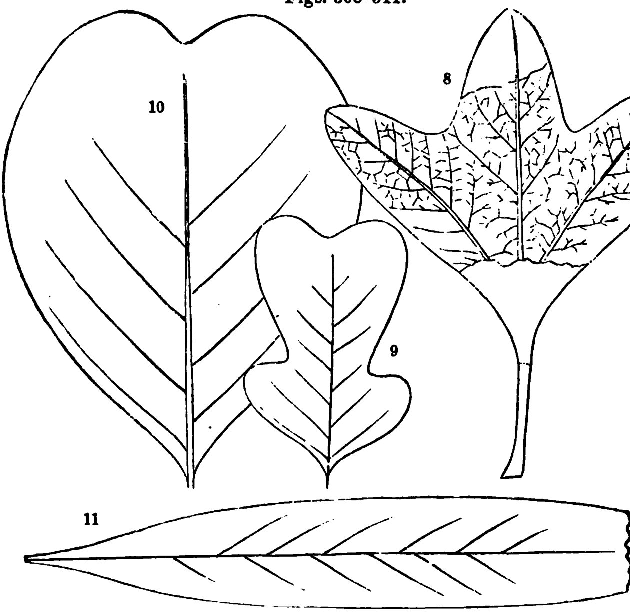
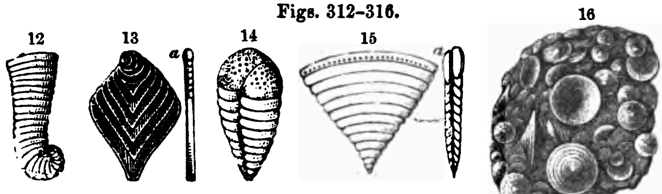


Fig. 308, Leguminosites Marcouanus; 309, Sassafras Cretaceum; 310, Liriodendron Meekii; 311, Salix Meekii.

these shells, the great majority of which do not exceed a pin's head in size. A few of the forms are represented in

Figs. 312–316.



RHIZOPODS: Fig. 312, Lituola nautiloidea; 313, Flabellina rugosa; 314, Chrysalidina gradata; 315, Cuneolina pavonia; 316, Orbitolina Texana.

figs. 312 to 316, all very much enlarged, except 316, which is natural size. A very common kind resembles fig. 99, p. 59, and is called a *Rotalia*. Fig. 316 represents a large disk-shaped species, called an *Orbitolina*, from Texas.

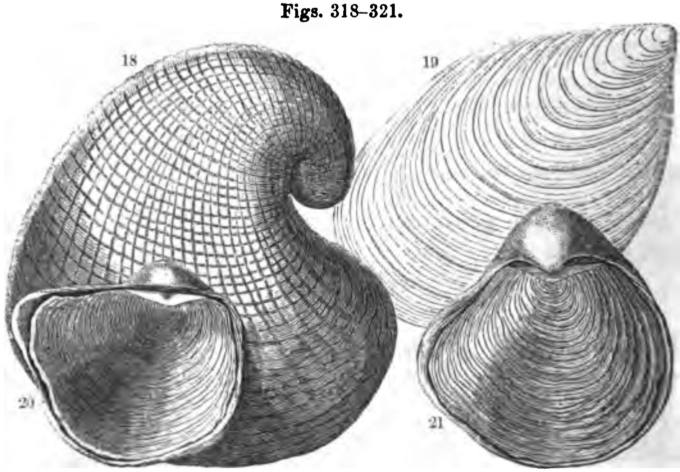
Besides the above Protozoans, Sponges were also very abundant, and their *siliceous spicula* (p. 58) were another important source of the silica of the flints. Fig. 317 represents one of the Sponges from the Chalk of Europe.

Fig. 317.

Siphonia lobata.

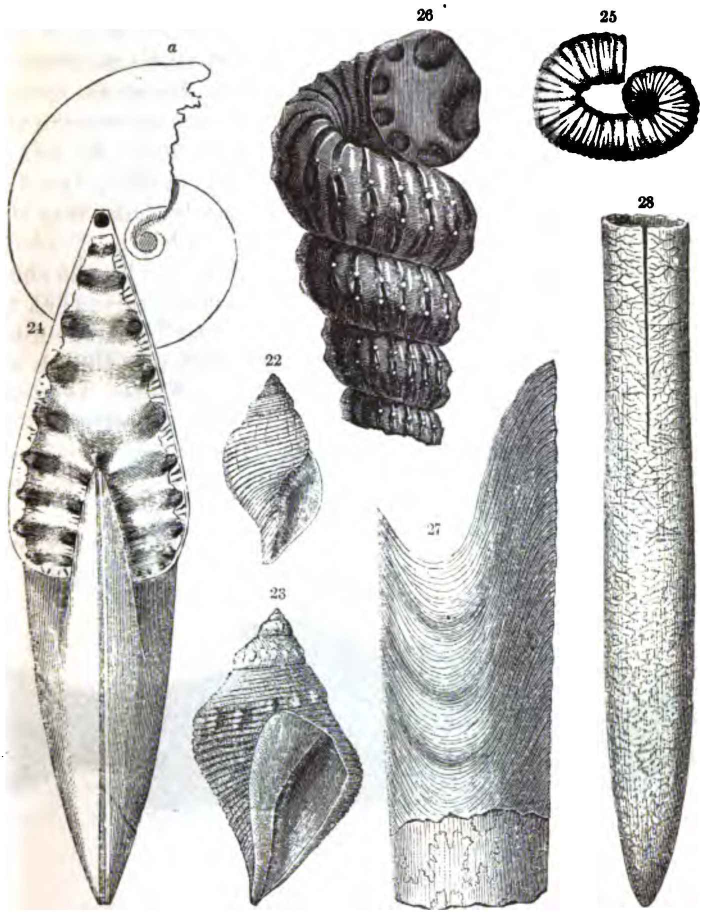
2. *Radiates — Mollusks.* — Corals and Echini were common among Radiates. Mollusks abounded, both of the Ammonite and Belemnite types, besides others of genera not peculiar to the Mesozoic. Many of the genera are identical with those represented in modern seas.

Figs. 318–321.



MOLLUSKS: Fig. 318, Exogyra costata; 319, Inoceramus problematicus; 320, Gryphæa vesicularis; 321, G. Pitcheri.

Figs. 322–328.

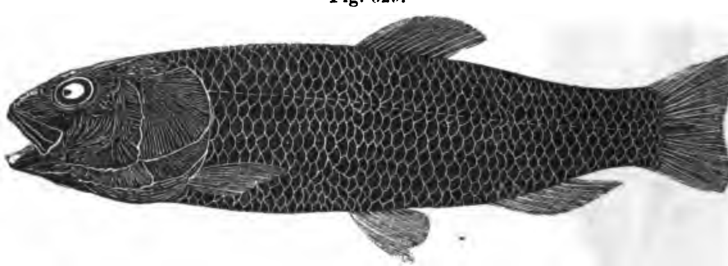


Mollusks: Fig. 322, Fasciolaria buccinoides; 323, Fusus Newberryi; 324, Ammonites Placenta; 324 *a*, id., in profile, reduced; 325, Scaphites larvæformis; 326, Turrilites catenatus; 327, Baculites ovatus; 328, Belemnitella mucronata.

Figs. 318–321 are of some of the most characteristic Conchifers from the American Cretaceous; fig. 318, an *Exogyra;* fig. 319, an *Inoceramus;* figs. 320, 321, *Gryphæas:*—genera that are now extinct. Figs. 322, 323 represent shells of Gasteropods, and 324 to 328, Cephalopods,—all American except 326; fig. 324, an upper front view of an *Ammonite,* showing the pockets along the sides of one of the partitions; fig. 324 *a,* a reduced view of the same Ammonite in profile; figs. 325 to 327, three species of the Ammonite family, but not of the genus *Ammonites,*—one, fig. 325, being called a *Scaphites* (from the Latin *scapha,* a *skiff*), an Ammonite with the shell looking as if partly uncoiled, and thus made somewhat to resemble a boat; fig. 326, a *Turrilites,* or *turreted* Ammonite, an anomaly in the family, as the species are almost all coiled in a flat plane; fig. 327, a *Baculites,* or *straight* Ammonite, so named from the Latin *baculum,* a *walking-stick.* Fig. 328 represents a very common New Jersey species of *Belemnites.* Some of the Ammonites of the Cretaceous period are 3 to 4 feet in diameter.

3. *Vertebrates.*—Among Vertebrates appeared the first of

Fig. 329.



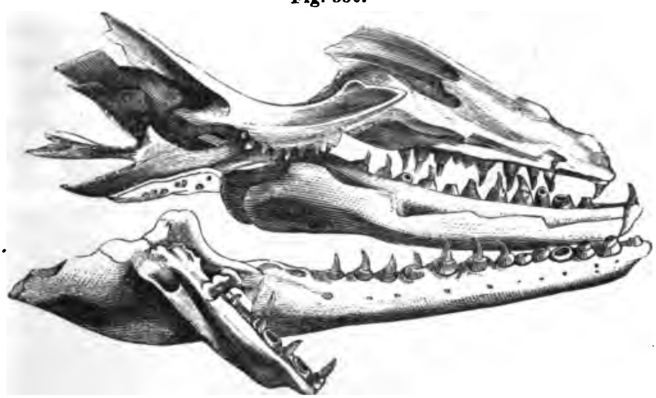
Osmeroides Lewesiensis (× ¼).

the *Teliost* or *Osseous Fishes,*—fishes allied to the perch, salmon, pickerel, etc. They occur along with numerous Sharks of both ancient and modern types (Cestracionts and

Squalodonts), and many also of Ganoids. Thus the ancient and modern forms of Fishes were united in the population of the Cretaceous seas, the former, however, making hardly more than a tenth of the species. Fig. 329 represents one of these Teliost Fishes, related to the *Salmon* and *Smelt*, from the Chalk at Lewes, England. There were also *Herring*, and many other kinds.

The Reptiles included species of some of the Jurassic genera, as *Pterodactyls*, *Ichthyosaurs*, *Plesiosaurs*, and the

Fig. 330.



Mosasaurus Hofmanni (× 1/18).

Iguanodon; also of other genera, as *Mosasaurs* (fig. 330), and true *Crocodiles*.

No remains of Mammals or Birds have yet been gathered from the Cretaceous formation.

3. General Observations.

1. **Geography.**—In North America the position of the Cretaceous beds along the borders of the Atlantic south of New York, near the Mexican Gulf, and also over a large part of the Rocky Mountain region, indicates that these border

regions and the Western Interior were under water when the period opened, as represented in the following map (fig. 331). The shaded part of the continent exhibits the extent to which it was submerged. (This map should be compared with that on page 73). It shows that the Chesapeake and Delaware Gulfs were in the ocean; that Florida was still under water; that the region of the Missouri River was a salt-

Fig. 331.

North America in the Cretaceous Period; MO, Upper Missouri region.

water region; that in fact the Rocky Mountains were at least 6000 or 7000 feet lower than now, the Cretaceous beds having now this elevation upon them. The Mexican Gulf spread over a large part of Georgia, Alabama, and Mississippi, extended northward to the mouth of the Ohio, and then west of Missouri and Kansas stretched far north over the present slopes of the great Western mountains, reaching perhaps to the Arctic, though on this point the evidence is not yet decisive. The deposits, excepting those of Texas, appear to be of seashore and off-shore formations; the Texan compact limestones were probably formed in *clear* interior waters.

In Europe the Chalk appears to have been accumulated in an open sea, where the water was one or more hundred feet deep. The material of the Chalk has been stated on page 190 to be mainly the shells of Rhizopods, and that of the associated flint to have been derived from Diatoms and Sponges. Rhizopods and Diatoms are now living in many parts of the ocean, over the bottom, even where the depth is thousands of feet, and are making accumulations of vast area. There appear, hence, to be in the present seas the conditions requisite for making chalk and also flint. The many Sponges, Echini, and Shells found in the Chalk beds are evidence, however, that the depth was not thousands of feet, although it may have been a few hundreds. The fossils of the Chalk are in many regions turned into flint, and some hollow specimens are filled with quartz-crystals, or agate

2. **Climate.**—The corals and other tropical life of the British rocks indicate that the seas were at least warm-temperate to latitude 60° north on the east side of the ocean. On the American side it appears to have been cooler, as it now is, in corresponding latitudes; and still the temperature was considerably warmer than the present. The warm oceanic zone which spread over the British seas appears, from the distribution of the fossils, to have reached the North American coast south of Long Island, and perhaps had no place on the coast north of Cape Hatteras. The plants of the Upper Missouri region indicate a warm-temperate climate over that territory.

GENERAL OBSERVATIONS ON THE MESOZOIC.

1. **Time-Ratios.**—The ratios between the Paleozoic ages as to the length of time that elapsed during their progress, or their *time-ratios*, are stated on p. 145 as probably not far from 3 : 1 : 1.

The American Mesozoic formations are too imperfect to be used as data for calculating the Mesozoic *time-ratios;* and in Europe there is much uncertainty as to the actual thickness of the rocks. Calculating from the best estimates of the thickness which have been given, the *time-ratio* between the Paleozoic and Mesozoic is nearly 3½ : 1; and between the Triassic, Jurassic, and Cretaceous periods, 1 : 1¼ : 1. That is, Mesozoic time was hardly one-third as long as the Paleozoic; and the three periods of the Mesozoic were not far from equal, the Jurassic being one-quarter the longest.

2. **American Geography.**—On page 162 it is remarked that the Mesozoic formations were confined to the Atlantic and Gulf border regions, and to an interior region west of the Mississippi covering much of the Rocky Mountain area, and that the intermediate portion of the continent had probably become part of the dry land. The facts which have been presented in the preceding pages have sustained this statement. The Triassico-Jurassic beds, as has been shown, lie in long narrow strips between the Appalachians and the coast, and spread widely over the Rocky Mountain region. The Cretaceous beds cover the Atlantic and Gulf borders, and also, like the Triassic, a very large part of the slopes of the Rocky Mountains. The eastern half of the continent during the Mesozoic was, therefore, receiving rock-formations only along its borders, while the western half had marine deposits in progress over its great interior. None of the American Mesozoic deposits bear any evidence that they were formed in a deep ocean. They appear to have been formed along coasts, or in shallow waters off coasts, or

in shallow inland seas; and only the Cretaceous limestone of Texas indicates a pure open, though not deep, sea, like that required for coral-reefs.

The Appalachians—the *eastern* mountains of the continent —had nearly their present elevation before the early Mesozoic beds commenced to form (p. 185). But the region of the Rocky Mountains—the *western* chain—was to a great extent still a shallow sea even during the Cretaceous period, or when the Mesozoic era was drawing to its close (p. 197).

Only one series of mountain-elevations can be pointed out, with our present knowledge, as originating in eastern North America in the course of the Mesozoic era, although great oscillations of level were much of the time in progress (p. 185). This one is that of the Mesozoic red sandstone and trap along the Atlantic border region. The trap ridges, ranging through the Connecticut valley from New Haven, Ct., to northern Massachusetts, that of the Palisades on the Hudson, and those connected with the early Mesozoic rocks of New Jersey, Pennsylvania, Virginia, North Carolina, and Nova Scotia, appear to date from a common epoch (p. 185). They conform to a common system, being parallel to the Appalachian chain through its varying courses, and not following one special compass-course. The epoch of their formation probably divides off the Triassico-Jurassic period of North America from the Cretaceous.

The study of the Pacific border of the continent will probably make known one or more additional mountain-ranges of Mesozoic origin.

3. **European Geography.**—Europe has its Mesozoic rocks distributed in patches, or in several independent or nearly independent areas, which show that it retained its condition of an archipelago throughout Mesozoic time. The oscillations of level, as indicated by the variations in the rocks,—variations both as to the nature of the beds and their distribution,—were more numerous and irregular than in North

America. The mountain-elevations formed, however, were few and small compared with those that followed either the Paleozoic or Mesozoic era. One series of disturbances is referred to the close of the Triassic, and another to the close of the Jurassic.

Among the Mesozoic formations of the European continent there are deposits of all kinds,—those of seashores; of off-shore shallow waters; of inland seas; of moderately deep oceanic waters; and of marshy, or dry and forest-covered, land.

Both in America and Europe there were some coal-beds made, though of small extent compared with those of the Carboniferous age

4. **Life.**—The Mesozoic era witnessed—(1) the decline of some ancient, or Paleozoic, types, of both plants and animals, (2) the increase and culmination of medieval or Mesozoic types, and (3) the beginning of some of the most important of modern or Cenozoic types.

(1.) *Disappearance of Ancient or Paleozoic features.*—Among the ancient tribes of plants the *Calamites*, or tree-rushes, and several genera of Ferns, disappear in the Jurassic. Among the old Brachiopod tribes the *Spirifer* and *Leptæna* families end in the Triassic; and among higher Mollusks the Silurian type of *Orthoceras*, and Devonian of *Goniatites*, have their last species in the Triassic.

(2.) *Progress in Mesozoic features.*—The *Cycads*, among plants, were those most characteristic of the Mesozoic: they afterwards yield to other kinds, and are now nearly an extinct tribe. The *Cephalopods*, among Mollusks, existed in vast numbers, both those with external shells, as the *Ammonites*, and those without, as the *Belemnites*. The whole number of species of Cephalopods now known from the Mesozoic formations is nearly 1200. Of these, about 950 were of the Nautilus and Ammonite families. Since the Cretaceous period no Ammonite has existed, and at the present time there are only 2 or 3 species of Nautilus. The whole number of species of Cephalopods living in the course of the Mesozoic era may have been three or four times 1200, as only a part would have been preserved as fossils. The sub-kingdom of Mollusks, therefore, culminated in the Mesozoic era; for its highest order, that of the Cephalopods, was then at its maximum.

The type of Reptiles was another that expanded and reached its height—that is, its maximum in number, variety, and rank of species—and commenced its decline in the Mesozoic era.

There were huge swimming Saurians, Enaliosaurs, in the place of whales in the sea; bat-like Saurians or Pterodactyls flying through the air; and four-footed Saurians, both grazing and carnivorous, many of them 25 to 50 feet long, occupying the marshes and estuaries. In the era of the Wealden and Lower Cretaceous there lived, in and about Great Britain, 4 or 5 species of Dinosaurs 20 to 50 feet long, 10 to 12 Crocodilians, Lizards, and Enaliosaurs 10 to 50 or 60 feet long, besides Pterodactyls and Turtles; and many more than this, since all that lived would not have left their remains in the deposits. To appreciate this peculiarity of medieval time, it should be considered that in the present age Britain has no large Reptiles; in Asia there are only *two* species over 15 feet in length; in Africa but *one;* in all America but *three;* in the whole world not more than *six;* and the largest of the six does not exceed 25 feet in length. The Mesozoic era is well named the *Age of Reptiles*.

All the Mesozoic animals, excepting the Mammals, belong to the *Oviparous* divisions; and the Mammals were mainly Marsupial species,—that is, *semi-oviparous* Mammals, as explained on p. 50,—species quite in harmony, therefore, with the other life of the era. The Birds of the age, or at least some of them, partook of the reptilian features of the time, having long tails like the associated Reptiles (though feathered tails), and possessing some other peculiarities of the scaly tribes. The long-tailed birds and Pterodactyls were the flying creatures of the age; the Ichthyosaurs and Plesiosaurs, and the like, the "great whales;" the Teleosaurs, Iguanodon, and other gigantic species of the estuaries and marshes, the creeping species. These, along with the small Marsupials and Insectivores of the Cycadean and Coniferous forests, were the more prominent kinds of Mesozoic life.

(3.) *Introduction of Cenozoic features.*—Among *Plants* the first of *Angiosperms*, (or the order including all trees having a bark (Oak, Maple, Apple, &c.), excepting the Conifers) and the first of *Palms*, are found in the Cretaceous. These become the characteristic plants of the Cenozoic era and Age of Man.

Among *Vertebrates* there were the first of the great order of Teliost or Osseous Fishes in the Cretaceous (p. 194), all previous species being either Selachians (Shark tribe) or Ganoids; the first of the modern tribe of Sharks in the Jurassic; the first of the modern genus of *Crocodilus* in the Jurassic; the first of Birds in the Triassic or Jurassic,—the reptilian Birds; the first of Mammals in the Triassic,—Marsupials, or semi-oviparous Mammals, along with some Insectivores.

Of the classes of Vertebrates, Fishes and Reptiles commence in the middle and later Paleozoic, and Birds and Mammals in the early or middle Mesozoic.

DISTURBANCES AND CHANGES OF LEVEL CLOSING MESOZOIC TIME.

At the close of the last period of the Mesozoic era—the Cretaceous—there was an extermination of the species then on the globe, which was as complete as that closing the Paleozoic era. No species have yet been proved to have survived from the Cretaceous into the Cenozoic era, except possibly some kinds of Sharks. The species most likely to have outlived the period of disturbance which intervened are the species of the open ocean, as Sharks, since variations in the climate of the globe and changes of level over its surface affect but slightly the ocean's waters remote from coasts.

Besides the destruction of species, there was the final extinction of several families and tribes. The great family of Ammonites, and many others of Mollusks, all the genera of Reptiles excepting *Crocodilus*, and others in all departments of life, came to their end in the revolution.

From the occurrence of Cretaceous rocks in the structure of mountains or about their tops, and the existence of marine rocks of the next (or Tertiary) period only at low levels upon the sides, or towards the foot, of the same mountains, it has been discovered that the epoch of disturbance or revolution was remarkable for the number of great mountain-ranges which either began at that time their existence above the oceans, or else had their altitude greatly increased. The region occupied by a Cretaceous sea must have been raised into a mountain-elevation before seashore Tertiary strata could have been formed about its base. The Rocky Mountains and Andes, Himalayas and Alps, received a large part of their elevation subsequent to the Mesozoic era, and some considerable part immediately at the close of the Cretaceous period, although the elevation in the case of each of these great chains of the world was continued in progress through the Tertiary and afterwards.

The Himalayas have no known Cretaceous rocks in their structure; but Oolitic beds occur at a height of 14,000 to 18,000 feet, and extend along at these elevations for 400 miles. (Strachey.) The land may in part have made its emergence from the sea before the Cretaceous period began; whether so or not, it continued long after rising: the elevation of the western part of the chain about Cashmeer was not completed until after the Tertiary period had well advanced. The Apennines began their elevation about the middle of the Cretaceous period, but made the most of their altitude in the early Tertiary. The Andes have Cretaceo-oolitic beds about their higher slopes, proving also their elevation to have been essentially cotemporaneous with that of the Rocky Mountains and other highest mountains of the globe.

The facts will be better appreciated after a study of the Tertiary formations, which afford part of the evidence on which these conclusions are based.

Extermination of life.—The proofs of elevation are so many and so extensive that it is reasonable to infer that a great change of climate must also have taken place over the globe. The Arctic regions may have been elevated more than lower latitudes, for Tertiary rocks do not occur on the eastern borders of the American continent north of the parallel of 42° N. to show that the continent was then below its present level. The change of climate consequent on the *increase* of Arctic lands, and the increased number and height of mountain-chains, may, therefore, have been so great as to have proved a principal cause of the extinction of life that then took place both over the land and along the oceanic borders. Should the cold winds and cold oceanic currents of the northern part of the existing temperate zone penetrate for a single year into the tropical regions, they would produce a general extermination of the plants and animals of the land, and also of those of the coast and sea-borders, even to a great depth, as far as the cold oceanic currents extended. If a change of climate took place at the close of the Cretaceous, such as has been supposed, these very results would then have happened; moreover, the frigid air and waters would have found tropical life much nearer to the pole than now, even over Europe and a large part of the United States.

IV. CENOZOIC TIME.

1. **Age of Mammals.**—Cenozoic time covers but one age,—the age of Mammals.

2. **General characteristics.**—In the transition to this age the life of the world takes on a new aspect. Trees of modern types—Oak, Maple, Beech, etc., and Palms—unite with Conifers to make the forests; Mammals of great variety and size—Herbivores, Carnivores, and others, successors to the small semi-oviparous Mammals and Insectivores—tenant the land in place of Reptiles; true Birds and Bats possess the air in place of reptilian Birds and Pterodactyls; Whales and Teliost or common Fishes, with Sharks, mainly of modern type, occupy the waters in place of Enaliosaurs, and almost to the exclusion of the ancient tribes of Cestraciont Sharks and Ganoids.

It has already been shown that several of these modernizing features began to appear in the Mesozoic era. Thus, in all geological as well as other history (as remarked on page 154), every age has preparations for it in progress in the age preceding. There are no abrupt transitions. The Mammals, Birds, Teliosts, and Angiosperms of the Reptile world were precursors of a future and brighter era, when these species should be the predominant races. The type of Mammals appears in Cenozoic time under several successive faunas of different species, each successively exterminated, and finally expands till in number of kinds and in the magnitude of its wild beasts the Mammalian age far exceeds the Age of Man. These, also, disappear before the last age opens and during its early progress.

MAMMALIAN AGE.

The age of Mammals is divided into two Periods:—1. The *Tertiary;* 2. The *Post-tertiary.*

In the *Tertiary* the Mammals are all extinct species, and the other species of life mostly so; the number of living species of Invertebrates (Radiates, Mollusks, and Articulates) varies from *none* in the early part of the period to 90 per cent. in the latter part.

In the *Post-tertiary* the Mammals are nearly all of extinct species, but the Invertebrates are almost wholly of living species, not over 5 per cent. being extinct.

I. TERTIARY PERIOD.

1. Epochs.

The beds of the Tertiary period have been divided by Lyell into three series:—

1. EOCENE (from the Greek *eōs*, *dawn*, and *kainos*, *recent*). Species all extinct.

2. MIOCENE (from *meiōn*, *less*, and *kainos*): 15 to 40 per cent. of the species extinct.

3. PLIOCENE (from *pleiōn*, *more*, and *kainos*): 50 to 90 per cent. of the species extinct.

These subdivisions do not correspond to the epochs of the period, either in Europe or America, although affording convenient terms for *Lower*, *Upper*, and *Middle* Tertiary.

In North America the *epochs* are the following:—

1. CLAIBORNE, or that of the Tertiary beds of Claiborne, Alabama,—the *early Eocene.*

2. JACKSON, or that of the beds of Jackson, Mississippi,—the *Middle Eocene.*

3. VICKSBURG, or that of the beds of Vicksburg, Mississippi,—the *later Eocene.*

4. YORKTOWN, or that of the beds of Yorktown, Virginia, in which 15 to 30 per cent. of the species are living,—usually called *Miocene*, but probably including part, at least, of the Pliocene.

A fifth has been separated as *Pliocene*, or the SUMTER epoch, based on observations on the beds in Sumter and

Darlington districts, South Carolina; but it is probably not distinct from the Yorktown. (Conrad.)

2. Rocks: kinds and distribution.

The marine Tertiary beds of North America border the continent south of New England along both the Atlantic Ocean and the Mexican Gulf, like the Cretaceous. They overlie nearly all the Cretaceous beds on the Atlantic border, but extend less far inland on the Gulf border. (See map on p. 69, in which the area is lined obliquely from the left above to the right below). They spread northward along the Mississippi to the mouth of the Ohio, and also westward beyond this river into Texas, along the west side of the Mexican Gulf; but the *marine* Tertiary beds do not, like the Cretaceous, stretch north over the Rocky Mountain region. There are, however, about the Upper Missouri and over other parts of the slopes of these mountains, extensive deposits of *fresh-water* Tertiary, the lowest layers of which are of brackish-water origin. (On the map the area of this fresh-water Tertiary is distinguished by being more openly lined than those of the marine Tertiary.) The most northern locality of Tertiary on the Atlantic coast is on Martha's Vineyard. The Tertiary formation also occurs extensively in California and Oregon, and in some places has a height of 2000 feet above the sea.

The Eocene beds are best displayed in the Tertiary of the Gulf border from the Mississippi River to South Carolina, and the marine Miocene beds on the Atlantic border from New Jersey to South Carolina, though both occur in other parts of the Tertiary region. The fresh-water Tertiary of the Upper Missouri is at its base probably Eocene; it contains much lignite and many fossil leaves, like the lower Eocene elsewhere. The rest is Miocene and Pliocene.

The Tertiary beds are generally but little consolidated; they consist of compacted sand, pebbles, clay, earth that was once the mud of the sea-bottom or of estuaries, mixed often with shells,—being just such kinds of deposits as are now forming along the seashores and in the shallow bays and estuaries of the coast, or in the shallow waters off the coast. There are also some limestones made of shells; and others made of corals, resembling the reef-rock of coral seas. The latter are found mainly in the States bordering on the Mexican Gulf. Another variety of rock is the *buhrstone*, a very cellular siliceous rock, flinty in texture, used, on account of its being so hard and at the same time full of irregular cavities, for making mill-stones. It is found in South Carolina.

The Tertiary of Great Britain occurs mostly in the south-eastern part of England, in the London basin as it is called, and on the southern and eastern borders of the island, adjoining the Cretaceous.

On the continent of Europe the Paris basin is noted for its Eocene strata and fossil Mammals. Other Tertiary areas are those of the Pyrenean and Mediterranean regions, those of Switzerland, of Austria, etc. Some of the *marine* Eocene beds contain a fossil having the shape of a coin, called a Nummulite (from the Latin *nummus*, a *coin*). One is figured on page 59. Occasionally the beds are so far made up of these Nummulites that they are called *Nummulitic limestone*.

These marine Eocene strata spread very widely over both Europe, northern Africa, and Asia,—occurring in the Pyrenees, forming some of their summits; in the Alps to a height of 10,000 feet; in the Carpathians, in Algeria, in Egypt, where the most noted pyramids are made of Nummulitic limestone, in Persia, in the western Himalayas (the region of Cashmere), to a height of 15,000 feet. The later Tertiary formations are much more limited in distribution, and many are of terrestrial or fresh-water origin.

The rocks are similar to those of North America, but with more of compact sandstone and compact limestone. The sandstone is a very common building-stone in different parts of Europe, being soft enough to be worked with facility, yet generally hardening on exposure, owing to the fact that it contains calcareous particles (triturated shells), which render the percolating waters or rain calcareous, so that on evaporating they produce a calcareous deposit, as a cement, among the grains of sand.

The Eocene formation of southeastern England consists of bed of clay and sand, the lowest of sand sometimes containing rolled flints. The *Lower Eocene* includes the Thanet sands, Woolwich beds, London clay, and Bognor beds; the *Middle Eocene*, the Bagshot beds, Headon group, and others; the *Upper Eocene*, the Hempstead beds near Yarmouth. The *Older Pliocene* includes the Coralline crag and Red crag of Suffolk; and the *Newer Pliocene*, the Norwich crag, which is of fluvio-marine origin. No marine Miocene beds have yet been identified in Great Britain.

3. Life.

1. *Plants.*

The great feature of the vegetation is the prevalence of the class of Angiosperms, which made its first appearance in the Cretaceous. Leaves of *Oak*, *Poplar*, *Maple*, *Hickory*, *Dogwood*, *Mulberry*, *Magnolia*, *Cinnamon*, *Fig*, *Sycamore*, and many others, have already been found in both American and European Tertiary strata, besides the remains of Palms and Conifers. A leaf of a Tertiary Fan-palm (species of *Sabal*) found in the Upper Missouri must have been, when entire, 12 feet in breadth. Nuts are also common in some beds,—as at Brandon, Vermont. Fig. 332 is the leaf of an Oak; fig. 333, of a species of Cinnamon; fig. 334, of a Palm; fig. 335, the nut of a beech, closely like that of the common beech; fig. 336, another nut, from Brandon, of unknown relations.

The Eocene Plants in central and southern Europe have, in general, a striking resemblance to those of Australia, and the Miocene and Pliocene to those of America. The forests of England, in the Eocene, abounded in Palms.

The microscopic plants which form siliceous shells called Diatoms (p. 61) make extensive deposits in some places.

Figs. 332–336.

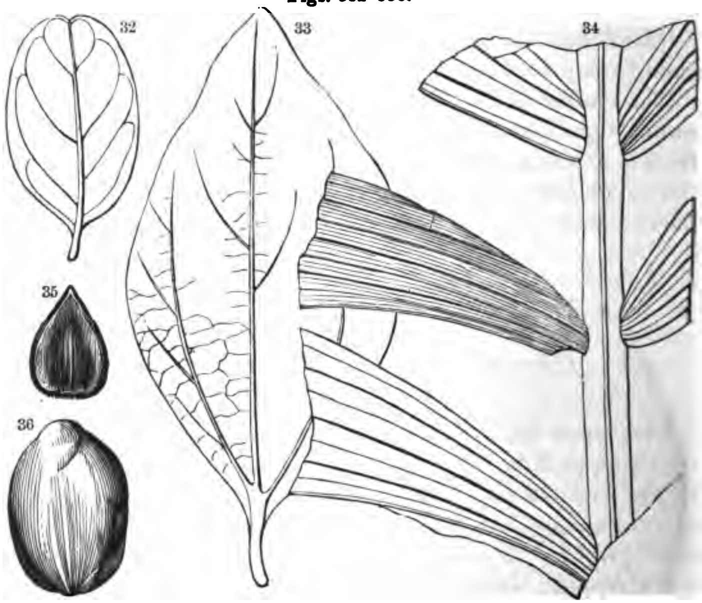


Fig. 332, Quercus myrtifolia?; 333, Cinnamomum Mississippiense; 334, Calamopsis Danæ; 335, Fagus ferruginea?; 336, Carpolithes irregularis.

One stratum near Richmond, Virginia, is 30 feet thick, and is many miles in extent; and another, near Bilin in Bohemia, is 14 feet thick. The material from the latter place was used as a polishing-powder (and called Tripoli, or polishing-slate) long before it was known that its fine grit was owing to the remains of microscopic life. Ehrenberg has calculated that a cubic inch of the fine earthy slate contains about forty-one thousand millions of organisms.

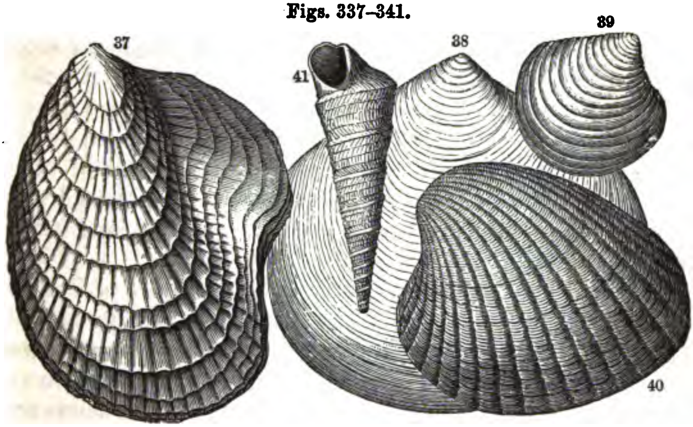
2. *Animals.*

The most prominent fact with regard to the Tertiary Invertebrates is their general resemblance to modern species. Although a number of the genera are extinct, and all the Eocene species, there is still a modern look in the remains, and the specimens have often the freshness of a shell from a modern beach.

The species of Tertiary shells found in the European beds number about 6000; while not over 3000 have been gathered from the North American beds.

The following are figures of a few species of the Claiborne epoch. Fig. 337 represents an Eocene *Oyster;* fig. 338, a species of *Crassatella;* fig. 339, an *Astarte;* fig. 340, a *Cardita;* and fig. 341, a *Turritella:* all are from Claiborne, Alabama.

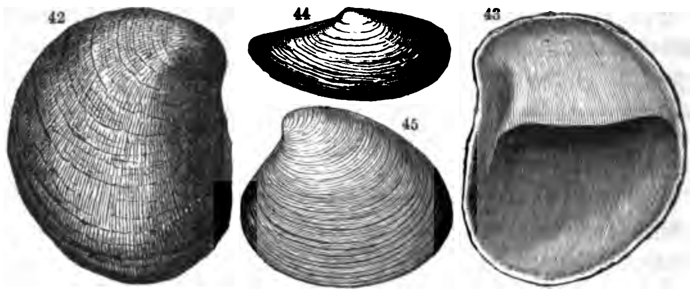
Figs. 337–341.



Mollusks: Fig. 337, Ostrea sellæformis; 338, Crassatella alta; 339, Astarte Conradi; 340, Cardita planicosta; 341, Turritella carinata.

Figures 342 to 345 are of species of shells of the Yorktown epoch, from Virginia; figs. 342, 343 represent a very

Figs. 342–345.



GASTEROPOD: Figs. 342, 343, Crepidula costata.—CONCHIFERS: Fig. 344, Yoldia limatula; 345, Callista Sayana.

common *Crepidula*, upper and under sides. The species of the epoch include the common *Oyster* and *Clam*, and other modern species; and these are, therefore, among the most ancient of living species on the globe; for, until the Miocene epoch opened, every species of Mollusk that had existed on the globe had become extinct, and every species of other kinds of life, if we except some Protozoans and Protophytes.

With regard to Vertebrates the points of special interest are the following:—

1. In the class of Fishes:—(1) The prevalence of *Teliosts*, or fishes allied to the Perch and Salmon, as already stated; and (2) the abundance of Sharks, some of them having teeth 6 inches long and broad. The teeth of sharks are the durable part of the skeleton; they are very abundant in both Eocene and Miocene beds. Fig. 59, p. 52, represents a tooth of the *Carcharodon angustidens*. The larger teeth above alluded to belong to the *Carcharodon megalodon*, and are found at different places on the Atlantic border from Martha's Vineyard south. Fig. 58 represents the tooth of

another common kind of Shark, a species of *Lamna* (*L. elegans*), from Claiborne.

In the class of Reptiles:—The existence of numerous *Crocodiles* and *Turtles*. The shell of one of the Miocene Turtles, found fossil in India, had a length of 12 feet, and the animal is supposed to have been 20 feet long. The first of *Snakes*, moreover, occur in the Eocene.

In the class of Birds:—The species found are not reptilian or long-tailed, but like modern birds; they are related to the *Pelican*, *Waders*, *Pheasants*, *Perchers*, *Vultures*. But fossil birds are of very rare occurrence; none have yet been found in America, although Mammalian remains are common.

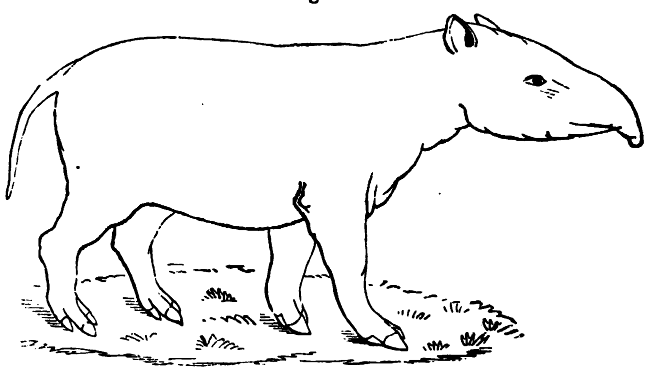
In the class of Mammals:—The occurrence of the first of *Whales*, the first of *Carnivores*, *Herbivores*, *Rodents*, *Monkeys*, and of other tribes, indicating a large population of brute animals wholly different from the present in species, though, in general, related to the modern kinds in form and structure. A few, however, are widely diverse from any thing in existence,—such combinations as the mind would never have imagined without aid from the skeletons furnished by the strata.

In the early Eocene there appear to have been more Herbivores than Carnivores; but afterward the Carnivores were as common as now.

Cuvier first made known to science the existence of fossil Mammals. The remains from the earthy beds about Paris had been long known, and were thought to be those of modern beasts. But, through careful study and comparisons with living animals, he was enabled to bring the scattered bones together into skeletons, ascertain the tribe to which they belonged, and determine the food and mode of life of the ancient but now extinct species. Cuvier acquired his skill by observing the mutual dependence which subsists between all parts of a skeleton, and, in fact, all parts of an animal. A sharp claw is evidence that the animal has trenchant or cutting molar teeth, and is a flesh-eater; a hoof, that he has broad molars and is a grazing species; and, further, every bone has some modification showing the group of species to which it belongs, and may thus be an indication, in the hands of one well versed in the subject, of the special type of the animal, and of its structure, even to its stomach within and its hide without.

One of these Paris beasts is called a *Paleothere* (from the Greek *palaios*, *ancient*, and *therion*, *wild beast*. Its form, as restored, is shown in figure 346. It is related to the modern Tapir, and was of the size of a horse. Another kind, called

Fig. 346.



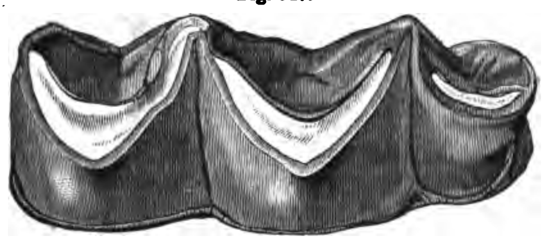
Palæotherium magnum.

an *Anoplothere*, was of more slender habit, and somewhat resembled a stag. There were others, related to the hog, or Mexican Peccary, and to the horse; also some Carnivores, a Bat, and an Opossum.

The only American *Eocene* Mammals that have been discovered are those of the ocean, as Whales. The bones of a species of whale, called a *Zeuglodon*, occur in many places in the Gulf States; and in Alabama the vertebræ were formerly so abundant as to have been built up into stone walls, or burnt to rid the fields of them. The living animal was probably 70 feet in length. One of the larger vertebræ measures a foot and a half in length and a foot in diameter.

The *Miocene* beds of the "Bad Lands" on the White River, in the Upper Missouri region, have afforded remains of a large number of Miocene quadrupeds. Among them, according to Leidy, there are eight Carnivores related somewhat to the *Hyena*, *Dog*, and *Panther;* 25 Herbivores, including 2 *Rhinoceroses*, and species approaching the *Tapir*, *Peccary*, *Deer*, *Camel*, *Horse;* and 4 Rodents, besides many

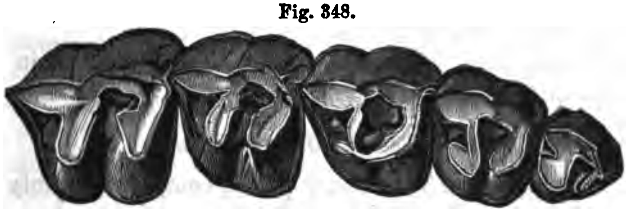
Fig. 347.



Tooth of Titanotherium Proutii (× ½).

Turtles. Figure 347 represents a tooth, half the natural size, of a *Titanothere*, an animal related to the Tapir and Paleothere, but of elephantine size, standing probably 7 or

Fig. 348.



Teeth of Rhinoceros Nebrascensis.

8 feet high. Figure 348 represents a few of the teeth of one of the Rhinoceroses.

Among Mammals of the European Miocene there were *Elephants*, *Mastodons*, *Deer*, and other Herbivores, many Carnivores, *Monkeys*, *Ant-eaters*, etc. One of the most singular species is the *Dinothere*, the form of the skull of which —the only part of the skeleton found—is shown in the annexed figure; its actual length is 3 feet 8 inches. It appears to have had a proboscis like an Elephant, but the tusks proceeded from the *lower* instead of upper jaw, and were bent *downward*. Some suppose it to have been related to the Elephant, and others to the marine Manatus and Dugong.

Fig. 349.

Dinotherium giganteum ($\times \frac{1}{20}$).

In fresh-water *Pliocene* beds of the Upper Missouri there are remains of a fauna totally different in species from that of the Miocene. It included a *Rhinoceros*, an *Elephant* of great size, a *Mastodon*, 3 species of *Camel*, 4 of the *Horse* family, *Deers*, a *Wolf*, a *Fox*, a *Beaver*, and a *Porcupine*, all of extinct species; it had, in its Camels and Rhinoceros and Elephant, quite an Oriental character, as Leidy observes, though still prominently North American in the preponderance of Ungulates, and the absence of the South American type of Edentates or Sloths.

The earliest of the Bovine or Ox group occur in the European Pliocene.

4. General Observations.

1. **Geography.**—The Tertiary period completed mainly the work of rock-making, along the borders of the continent, which had been in progress during the Cretaceous period. The accompanying map shows approximately the part of

the continent of North America under the sea when the Tertiary era began. By comparing it with the map of the

Fig. 350.

Map of North America in the early part of the Tertiary Period.

Cretaceous continent, p. 196, it is seen that the Rocky Mountain region had become dry land in the interval; but, as Hayden has shown by the discovery of brackish-water beds in the lowest Tertiary of the Upper Missouri region, the elevation was at first small; and its present height was gradually attained later in the Tertiary period. The great river-system of the Mississippi, embracing slopes from the Rocky Mountains on the west to the Appalachians on the east, then for the first time became complete. The Mexican Gulf was much larger than at present; but there was not that long extension far northward which it had during the Cretaceous period. Florida was still submerged, and also all the bays of the Atlantic coast south of New York. After the Eocene epoch the Mexican Gulf became much more contracted by an elevation of the coast along the Gulf; and by the close of the Tertiary period the continent appears to have reached nearly its present outline.

In the Orient the Eocene era was one of very extensive submergence of the land, as shown by the distribution of the marine beds over Europe, Asia, and northern Africa, as stated on page 208. After the Eocene, the greater part of these continental seas had become dry land, and in general continued so afterward; for the Miocene and Pliocene are, comparatively, very limited in extent. The fact that many of the great mountains of the globe, as the Pyrenees, Alps, Carpathians, Himalayas, etc., were only partly made, is here proved by their containing Eocene rocks in their structure, or by their bearing them about their summits.

By evidence of this kind,—the presence of Eocene strata,—it is learned that the elevation of the Pyrenees, though commenced before the close of the Cretaceous, was mainly produced in the middle or later part of the Eocene, as also that of the Julian Alps, the Apennines and Carpathians, and that of heights in Corsica. The elevation of the western Alps, including Mont Blanc, is referred by Elie de Beaumont to the close or latter part of the Miocene epoch; and that of the eastern Alps, along the Bernese Oberland, to the close of the Pliocene. An elevation of 3000 feet took place in Sicily after the Pliocene. The Himalayas, in their western part about Cashmere, have nummulitic or Eocene beds, at a height of 15,000 feet; so that even this great chain, although earlier elevated to the east, was not completed before the Middle Eocene; and even later than this, as later Tertiary beds at lower levels show, it received a considerable part of its elevation.

Many parts of the region of the Andes were raised 3000 to 5000 feet or more in the course of the Tertiary period.

Climate.—In Europe, the fact that the plants of the *Eocene* were Australian in character over its central and southern portions, and that Palms abounded in Britain, is evidence of a tropical or sub-tropical climate on the south, and sub-tropical or warm-temperate on the north.

Again, the plants of the *Miocene*, in southern Europe, are supposed to indicate a sub-tropical climate there during the middle Tertiary.

In North America, the *Eocene* palms and other plants of the Upper Missouri region show that the temperature now found in the Dismal Swamp in North Carolina characterized in the *early Tertiary* era the region of the Upper Missouri, the vicinity of the Great Lakes, and Vermont (where is the Brandon deposit of nuts and lignite).

The *Camels*, *Rhinoceroses*, and other animals of the *Pliocene* of the Upper Missouri seem to prove that a warm-temperate climate still prevailed there in that closing epoch of the Tertiary period. It is therefore plain that the Earth had not its present diversity of zones of climate; and Europe was apparently little if any colder in the Eocene than in the Jurassic era. If the interval between the Cretaceous and Tertiary was one of unusual cold, through Arctic and other elevations, as suggested on page 204, the cold epoch had mostly passed when the Eocene era opened.

II. POST-TERTIARY PERIOD.

1. **General characteristics.**—The Post-tertiary period was remarkable (1) as the period of culmination of the type of Mammals; and (2) as that of *high-latitude* movements and operations both north and south of the equator.

2. **Epochs.**—The epochs, as observed in North America, are two :—

1. The GLACIAL, or the epoch when, *over the higher lati-*

tudes, the continents underwent great modifications in the features of the surface through the agency of ice.

2. The CHAMPLAIN, an epoch when the ice had disappeared, and the same *high-latitude* portions of the continent, and to a less extent the lower, became covered by extensive *fluvial* and *lacustrine* formations, and also, in some places, by *marine*.

These epochs were followed in America by another,—the TERRACE epoch,—which forms a transition to the Age of Man; when these fluvial, lacustrine, and marine formations were made into terraced heights by an elevation of the continent which was also in the main a *high-latitude* movement.

1. GLACIAL EPOCH.

The special effects of the operations going on in the Glacial epoch are the following:—

1. *Transportation.*—The transportation of a vast amount of earth and stones from the higher latitudes to the lower, over a large part of the breadth of a continent.

The material consists of earth and pebbles, or stones, confusedly mingled or *unstratified*, and is called *drift*. It contains no marine fossils or relics.

New England, Long Island, Canada, New York, and the States west to Iowa and beyond, are in many parts thickly covered with *drift*; it reaches south to the latitude of 39°, or nearly to the southern limits of Pennsylvania, Ohio, Indiana, Illinois, and central Missouri, being hardly traceable south of the Ohio River.

The stones are of all dimensions, from that of a small pebble to masses as large as a moderate-sized house. One at Bradford in Massachusetts is 30 feet each way, and its weight is estimated to be at least 4,500,000 pounds. Many on Cape Cod are 20 feet in diameter. One lying on a naked ledge at Whitingham in Vermont measures 43 feet in length and 30 in height and width, or 40,000 cubic feet in bulk, and was probably transported across Deerfield valley, the bottom of which is 500 feet below the spot where it lies.

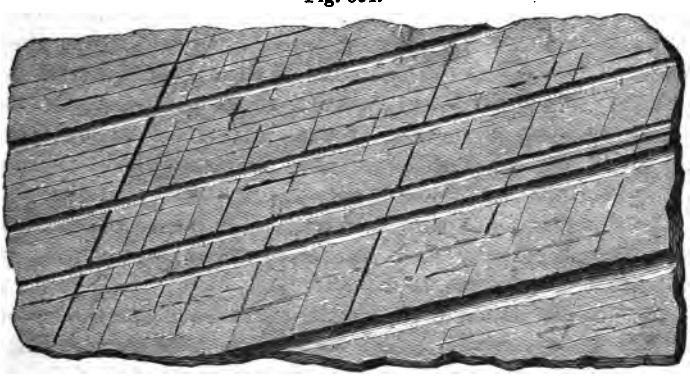
The drift-material is coarsest to the north.

The directions in which it travelled are in general between southwestward and southeastward, and mostly between southward and southeastward. The material was carried southward across the great lakes and across Long Island Sound, the land to the south, in each case, being covered with stones from the land to the north.

The distance to which the stones were transported, as learned by comparing them with the rocks in place to the north, is mostly between 20 and 40 miles, though in some cases 60 miles or more.

2. *Scratches.*—The rocky ledges over which the drift was borne are often scratched, in closely crowded parallel lines, as in the annexed figure (fig. 351). The scratchings or groov-

Fig. 351.



Drift groovings or scratches.

ings are often deep and broad channellings, at times even a foot in depth and several feet wide, as if made by a tool of great size as well as power. At Rowe in Massachusetts and on the top of Mount Monadnock, the scratches are of this remarkable character. These scratches occur wherever the drift occurs, provided the underlying rocks are sufficiently durable to have preserved them, and they are usually of great uniformity in any given region. Frequently two or more directions may be observed on the same surface, as if made at different epochs.

They are found in the valleys and on the slopes of mountains to a height, on the Green Mountains, of 5000 feet.

They often cross slopes and valleys obliquely,—that is, without following the direction of the slope or valley. But, when so, it is usually found that these valleys are tributary to some great valley to which the oblique scratches are more or less nearly parallel. For the courses of the scratches generally conform to the directions of the great valleys of the land, rather than to those of the smaller. Thus, in the Hudson River valley, between the Catskills and Green Mountains, the scratches have mostly the Hudson River course; and in the Connecticut River valley, between the Green Mountains and the heights of eastern Massachusetts, they conform in general to the course of the Connecticut valley.

While the courses are generally from the northward to the southward, like those of the drift, there are cases of eastward and westward scratches. Such occur on the elevations south of the Mohawk valley, near Cherry Valley, and over the bottom of the Mohawk valley, near Amsterdam, at various localities; they are here parallel to the course of the great Mohawk valley.

The stones, or boulders, are often scratched like the rocks.

European drift.—The drift in Europe presents the same general course and peculiarities as in North America. It reaches south to about latitude 50°. The region south of the Baltic, and parts of Great Britain, are covered with drift and stones from Scandinavia. The distance of travel varies from 5 or 10 miles to 500 or 600.

3. *Fiords.*—Fiords are deep narrow sea-channels, running

many miles into the land. They occur on the coasts of Norway, Britain, Maine, Nova Scotia, Labrador, Greenland, on the coast of western North America north of the Straits of de Fuca, and that of western South America south of latitude 41° S.

Fiords are thus, like the drift, confined to the higher latitudes of the globe; and the two may have been of cotemporaneous origin.

Origin of the drift.—Nothing but moving ice could have transported the drift with its immense boulders. Ice is performing this very work now in the *glacier* regions of the Alps and other icy mountains, and stones of as great size have in former times been borne by a slow-moving glacier from the vicinity of Mont Blanc across the lowlands of Switzerland to the slopes of the Jura Mountains, and left there at a height of 2203 feet above the present level of Lake Geneva. Moreover, there are scratches, of precisely the same character as to numbers, depth, and parallelism, in the granitic and limestone rocks of the ridges; and, besides, the transported material is left unstratified, when not afterwards acted upon and redistributed by Alpine torrents.

Icebergs also transport earth and stones, as in the Arctic seas; and great numbers are annually floated south to the Newfoundland banks, through the action of the northern or Labrador current, where they melt and drop their great boulders and burden of gravel and earth to make unstratified deposits. It is objected to icebergs as the cause of the phenomena of drift, that they could not have covered great surfaces so regularly with scratches, and, again, that there are no marine relics in the unstratified drift to prove that the continent was under the sea in the Glacial epoch.

There is a seeming difficulty in the Glacier theory, from the supposed want of a sufficient slope in the surface to produce movement. A slope, however, of one degree would be enough. The production of the degree of cold required to make a *glacial* epoch is an indication that the continent was considerably higher than it is now over its higher latitudes; and the fiords are other evidence to the same effect, since they must have been scooped out when the land was above the sea-level, so that running water or ice could have carried on the erosion by which they were made. If a great glacier, covering the land, had moved along through its extent but a single mile, it would have made scratches every where beneath it; and 50 miles are all that would have been required in order to have transported the boulders the distances they are known to have travelled in North America. The Connecticut valley appears to have been the course of one great independent glacier; the Hudson valley, of another; and the Mohawk valley, in the latter part of the epoch at least, of another.

2. Champlain Epoch.

The principal deposits of the Champlain epoch are of three kinds:—

(1.) *Alluvial*, or those formed along river-valleys by the action of the streams.

(2.) *Lacustrine*, or those formed about lakes.

(3.) *Sea-border* or *marine*, or those formed on or near sea-coasts, and often containing marine remains.

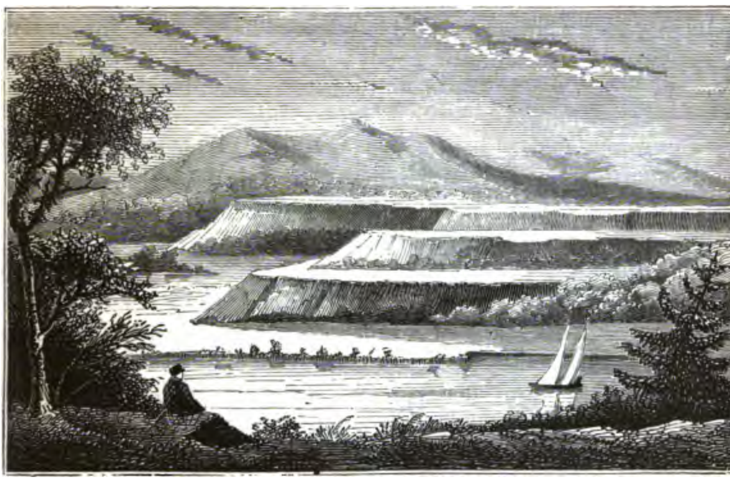
The *alluvial* deposits occur in all or nearly all the river-valleys within the drift latitudes of the North American continent, from Maine to Oregon and California; and they exist even farther south, in Kentucky and Tennessee, and perhaps in the Gulf States.

The beds consist of earth, clay, sand, or pebbles, or of mixtures of these materials. They *overlie* the unstratified drift wherever the two are in contact.

They form at present elevated alluvial flats on one or both sides of a river-valley. Their elevation above the bottom of the valley is greater in northern New England than in southern; and there is a like difference between those of the northern and southern parts of the States to the west of New England.

The flats have great extent along the Connecticut River and its various tributaries. The view in fig. 352 represents

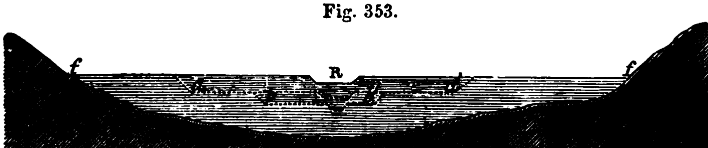
Fig. 352.



Terraces on the Connecticut River, south of Hanover, N. H.

a scene a few miles below Hanover in New Hampshire. There are here three different levels, or terraces, in the

Fig. 353.



Section of a valley in the Champlain epoch, with dotted lines showing the terraces of the Terrace epoch.

alluvial formation; the upper shows the total thickness of the formation down to the river-level.

Figure 353 represents a section of a valley, with the alluvial formation, *ff*, filling it, and the channel of the river at *R*. Were the country to be elevated, the river would dig out a deeper channel as the elevation went on, and thus the alluvial formation would finally be left far above the river, beyond the reach of its waters. The river would at the same time wear away a portion of the alluvium either side during its floods, and thus make room for a lower flat on its banks, over which the flooded waters would spread; for every river, not confined by rocks, has both its channel and its flood-ground.

The *lacustrine* deposits are of similar character, of like distribution over the continent, and in equally elevated positions above the present level of the water they border. The great lakes, as well as the smaller lakes of the country, are bordered by them.

The *sea-border* deposits are found along the borders of the sea, and often have the character of elevated beaches. They are found at many places on the coasts of New England, both southern and eastern. At several localities in Maine they afford shells at heights not exceeding 200 feet above the sea-level. They form deposits of great thickness along the St. Lawrence, as near Quebec, Montreal, and Kingston; at Montreal they contain numerous marine shells at a height of 400 to 500 feet above the river. They border Lake Champlain, being there 393 feet in height above its level; and, besides marine shells, the remains of a *whale* have been taken from the beds.

In the Arctic, similar deposits full of shells are common, at different elevations up to 600 or 800 feet, and in some places 1000 feet, above the sea-level.

These sea-border deposits, now elevated, must have been at the water-level, or below it, in the Champlain epoch. The facts prove that the river St. Lawrence was at that time an arm of the sea, of great breadth, with the bordering land

400 *to* 500 *feet below its present level;* that Lake Champlain was *a deep bay opening into the St. Lawrence channel, and that it had its whales and seals as well as sea-shells;* that the coast of Maine was 50 to 200 feet below its present level, and southern New England 30 feet or more.

The present elevated positions of the *alluvial* and *lacustrine* formations over the wide extent of the continent are equally good evidence that its *interior*, in the Champlain epoch, was below its present level.

There is thus proof that the whole northern portion of the continent was less elevated than now. In fact, the whole continent may have been lower; but, if so, the northern parts must have been most depressed, since the sea-border, alluvial, and lacustrine formations are all at higher elevations to the north, or near the northern boundary of the United States, than they are to the south.

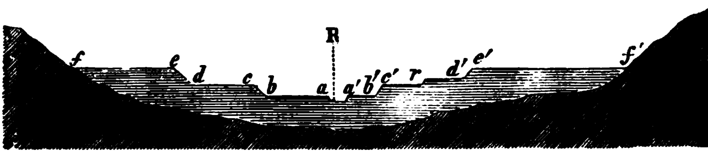
While, therefore, the facts connected with the *Glacial* epoch favor the view that the northern portions of the continent were then much *raised above their present level*, those of the next or *Champlain* epoch prove that it was afterwards *much below its present level.* We hence learn that there was an *upward* high-latitude movement for the Glacial epoch, and a *downward* for the Champlain epoch, and that the latter movement brought to its close the epoch of ice, by occasioning a warm climate.

3. Terrace Epoch.

When the Champlain epoch was in progress, the upper plain of the sea-border formations, now so elevated, was at the sea-level; and the high alluvial plains along the rivers were the flood-grounds of the rivers. Since then the land has been raised; and during the progress of the elevation the alluvial formations were cut into *terraces*, as represented in fig. 352, p. 225, and the sea-border formations, also, were cut into other terraces, or plains, of different levels. The epoch of this elevation is hence called the *Terrace* epoch. It constitutes the transition to the Age of Man.

In figure 353 there are dotted lines showing the levels of the river and its flood-plain at different periods in this elevation; and fig. 354 represents the terraces completed. The successive terraces are not necessarily evidence of as many

Fig. 354.



Section of a valley with its terraces completed.

successive elevations of the continent, yet may be so in some cases.

As already stated, the alluvial formations *throughout the continent*, along its various rivers and lakes, are raised high above the present flood-plains of the rivers or lakes, and to a greater height in the northern portions of the country than in the southern. Hence, while the Champlain epoch was one of a low level in the continent, especially at the north, the Terrace epoch was one of a rising again until the continent reached its present height; and this rising was greatest at the north.

The high-latitude oscillations of this part of geological history were hence an *upward* movement for the Glacial epoch; a *downward* for the Champlain epoch; an *upward* again for the Terrace epoch. There is no evidence that the movement resulted anywhere in the raising of a mountain-range; there was simply a gentle rising, then a sinking, and then a rising again of the general surface.

4. Champlain and Terrace Epochs in Europe.

There are elevated alluvial, lacustrine, and sea-border formations, of great extent, in Britain and over the higher latitudes of Europe, and also other evidence that these epochs were there represented by phenomena similar to those of America. But the limits of the epochs have not been made out, and are probably less clearly defined. The Glacial epoch may have been more prolonged, and the grander northern oscillations complicated by local changes of level. Europe has had its lofty glacial mountains ever since the closing Tertiary period. It is not improbable that the existing glaciers of Norway and the Alps are *continuations* of portions of the more ancient glaciers of the continent. After the Champlain epoch there was a time of unusual cold in Europe; and a glacier then covered all Switzerland between the Alps and the Juras (p. 223); for the transported stones and earth of the glacier cover the *alluvial* and *lacustrine* deposits. The simplicity observed in the order of events in American geological history is not found in any part of the European.

Among the British terraces those of Glen Roy in Scotland, called *Parallel roads*, or *Benches*, are especially noted. There are three, one above the other; the highest 1139 feet above tide-level, the second 1039 feet, the third 847 feet. Others exist along many of the rivers and about the lakes, as well as on the sea-borders.

LIFE OF THE POST-TERTIARY.

The invertebrate species of the Post-tertiary, and probably the plants, were nearly or quite all identical with the existing species. The shells and other invertebrate remains found in the beds on the St. Lawrence, Lake Champlain, and the coast of Maine, are all similar to those now found on the Labrador and Maine coasts.

The life of the period of greatest interest is the Mammalian, which type, as already remarked, then culminated. This culmination appears in—(1) the number of species, (2) the multitude of individuals, (3) the magnitude of the animals,—the period in each of these particulars exceeding the present age.

The remains in America have not been found in the unstratified drift, but only in the overlying Champlain deposits, or possibly those of more recent origin. In Europe they are not excluded from the drift.

1. *Europe and Asia.*—The bones of Mammals are found in caves that were their old haunts; in drift and alluvium; in sea-border deposits; in marshes, where the animals appear to have been mired; in ice, preserved from decay by the intense cold.

The caves in Europe were the resort especially of the Great Cave Bear (*Ursus spelæus*), and those of Britain of the Cave Hyena (*Hyæna spelæa*). Into their dens they dragged the carcases or bones of other animals for food, so that relics of a large number of species are now mingled together in the earth, or stalagmite, which forms the floor of the cavern. In a cave at Kirkdale, England, portions of at least 75 Hyenas have been made out, besides remains of an *Elephant*, *Tiger*, *Bear*, *Wolf*, *Fox*, *Hare*, *Weasel*, *Rhinoceros*, *Horse*, *Hippopotamus*, *Ox*, and *Deer*, all of which are extinct species. A cave at Gaylenreuth is said to have afforded fragments of at least 800 individuals of the Cave Bear.

The fact that the numbers of species and of individuals in the Post-tertiary was greater than now, may be inferred from comparing the fauna of Post-tertiary Great Britain with that of any region of equal area in the present age. The species included gigantic *Elephants*, two species of *Rhinoceros*, a *Hippopotamus*, three species of *Oxen*, two of them of colossal size, the *Irish Elk* (*Megaceros Hibernicus*), whose height to the summit of its antlers was 10 to 11 feet, and the span of whose antlers was 8 feet, or twice that of the American Moose, *Deer*, *Horses*, *Boars*, a *Wild-cat*, *Lynx*, *Leopard*, a *Tiger* larger than that of Bengal, a large *Lion* called a *Machærodus*, having sabre-like canines sometimes

8 inches long, the *Cave Hyena*, *Cave Bear*, besides various smaller species.

The Elephant (*Elephas primigenius*) was nearly a third taller than the largest modern species. It roamed over Britain, middle and northern Europe, and northern Asia even to its Arctic shores. Great quantities of tusks have been exported from the borders of the Arctic sea for ivory. These tusks sometimes have a length of 12½ feet. Near the beginning of the century, one of these Elephants was found frozen in ice at the mouths of the Lena; and it was so well preserved that Siberian dogs ate of the ancient flesh. Its length to the extremity of the tail was 16⅓ feet, and its height 9½ feet. It had a coat of long hair. But no amount of hair would enable an Elephant now to live in those barren, icy regions, where the mean temperature in winter is 40° F. below zero.

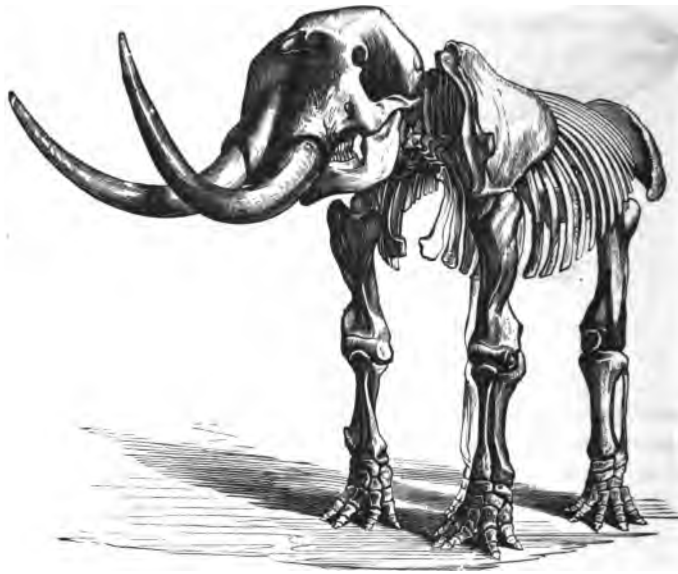
Although there were many Herbivores among the Post-tertiary species of the Orient, the most characteristic animals were the great *Carnivores*. The period was the time of triumph of brute force and ferocity, and the Orient—and perhaps especially the part of it in which lay Britain and Europe—was the *scene* of its triumph.

2. *North America.*—There were great *Elephants* and *Mastodons*, *Oxen*, *Horses*, *Stags*, *Beavers*, and some *Edentates*, in Post-tertiary North America, unsurpassed in magnitude by any in other parts of the world. *Herbivores* were the characteristic type. Of *Carnivores* there were comparatively few species; no bone-caverns have been discovered. Figure 355 (from Owen) represents the specimen of the American *Mastodon* now in the British Museum. The skeleton set up by Dr. Warren in Boston has a height of 11 feet and a length to the base of the tail of 17 feet. It was found in a marsh near Newburgh, New York. The American *Elephant* was fully as large as the Siberian.

3. *South America.*—South America had its Carnivores, its

Mastodons, and other Herbivores; but it was most remarkable for its *Edentates*, or Sloths, which were wonderful both

Fig. 355.



Skeleton of Mastodon giganteus.

for their magnitude and numbers. Fig. 356 shows the form and skeleton of one of these animals,—the *Megathere*. It exceeded in size the largest Rhinoceros: a skeleton in the British Museum is 18 feet long. It was a clumsy, sloth-like beast, but exceeded immensely the modern sloth in its size. Another kind of Edentate had a shell like a turtle, and was somewhat related to the Armadillo. One of them is called a *Glyptodon* (fig. 357). The animals of this kind were also gigantic, the Glyptodon here figured having had a length, to the extremity of the tail, of *nine* feet.

South America was eminently the continent of *Edentates*.

4. *Australia*.—Post-tertiary Australia contained Marsupial animals almost exclusively, like modern Australia; but

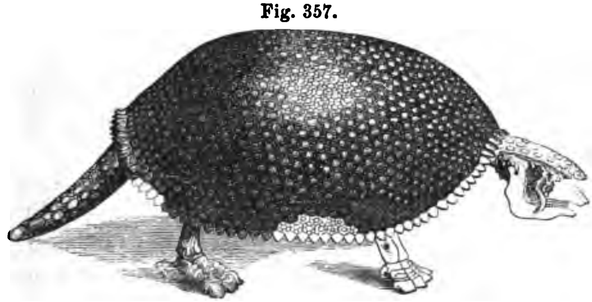
Fig. 356.

Megatherium Cuvieri ($\times \frac{1}{75}$).

these partook of the gigantic size so characteristic of the Mammalian life of the period. One species, called *Diprotodon*, was as large as a Hippopotamus.

Conclusions.—The facts sustain the following conclusions:

Fig. 357.



Glyptodon clavipes ($\times \frac{1}{30}$).

—(1.) The Post-tertiary period was the culminant time of Mammals, both as to their numbers and magnitude.

(2.) Each continent was gigantic in that type of Mammalian life which is now eminently characteristic of it: The Orient, in *Carnivores*, and, it may be added, *Quadrumanes* or *Monkeys;* North America, in *Herbivores;* South America, in *Edentates;* Australia, in *Marsupials*.

(3.) The climate of Great Britain and Europe, where were the haunts of *Lions*, *Tigers*, *Hippopotamuses*, etc., must have been warmer than now, and probably *not colder than warm-temperate*. The climate of Arctic Siberia was such that shrubs could have grown there to feed the herds of Elephants, and hence *could not have been below sub-frigid*, for which degree of cold it is possible the animals might have been adapted by their hairy covering.

(4.) The meridian time of the Post-tertiary Mammals was, hence, one of warmer climate over the continents than the present, and much warmer than that of the Glacial epoch. The species may have begun to exist before the Glacial epoch ended in Europe, but belonged pre-eminently to the Champlain epoch, when the lower level of the land over the higher latitudes would have occasioned a warm climate.

GENERAL OBSERVATIONS ON THE CENOZOIC ERA.

1. *Contrast between the Tertiary and Post-tertiary periods in geographical progress.*—The review of Cenozoic time has brought out the true contrast in the results of the Tertiary and Post-tertiary periods.

The Tertiary carried forward the work of rock-making and of extending the limits of dry land southward, southeastward, and southwestward, which had been in progress through the Cretaceous period, and, indeed, ever since the Azoic age.

The Post-tertiary transferred the scene of operations to the broad surface of the continent, which had been long in course of preparation, and especially to its middle and higher latitudes.

Through the Tertiary the higher mountains of the globe had been rising and the continents extending; and hence the great rivers with their numerous tributaries—which are the offspring of great mountains on great continents—began to exist and to channel out the mountains and make valleys and crested heights. In the Glacial epoch this work went forward with special energy. The exposed rocks were torn to fragments by the frosts and moving ice, or, in regions beyond the reach of glaciers, by the torrents; the earth and boulders formed were borne over the surface, and the excavation of valleys was everywhere in progress. In the Champlain epoch, the low level at which the land lay, and the gradual disappearance of the ice, enabled the flooded streams to fill the great valleys deep with alluvium. In the Terrace epoch, which followed, the upward movements of the land terraced the alluvial deposits along the river-valleys and about the lakes, and completed the action of the rivers and vegetation in spreading fertility over the land.

Thus, under the rending, eroding, and transporting power of fresh waters, frozen and unfrozen,—the great Post-tertiary agent,—in connection with high-latitude oscillations of the earth's crust, the surface of the earth was brought into a state of preparation for the Age of Mind.

2. *Life.*—In the Cenozoic era, as in the preceding, exterminations took place at several successive times, and were followed by new creations. The Mammals of the early Eocene are wholly distinct from those of the later; and these were distinct from any of the Miocene, the Miocene from the Pliocene, and the Post-tertiary from the Pliocene.

According to the present state of discovery, Mammals commenced in the Mesozoic era, late in the Triassic period, and the Mesozoic species were all *Marsupials* or *Insectivores.* They were the precursor species, prophetic of that expansion of the new type which was to take place after the Age of Reptiles had closed. In the early Eocene, at the very opening of the Age of Mammals, appeared Herbivores and Carnivores of large size. The Herbivores were mostly Pachyderms, related to the Tapir and Hog, and distantly to the Stag. The true Stag-family among Ruminants, and the Monkeys, commenced in the Miocene, or possibly in the later Eocene; the Elephant tribe, in the Miocene; the Bovine or Ox family, in the Pliocene, or late in the Tertiary. The last group seems to be more than all others especially adapted to man's necessities; and it was accordingly among the last of the types introduced on the globe.

V. ERA OF MIND—AGE OF MAN.

With the creation of Man a new era in Geological history opens. In earliest time only *matter* existed,—dead matter. Then appeared *life*,—unconscious life in the plant, conscious and intelligent life in the animal. Ages rolled by, with varied exhibitions of animal and vegetable life. Finally Man appeared, a being made of *matter* and endowed with *life*, but, more than this, partaking of a *spiritual nature*. The systems of life belong essentially to time, but Man, through his spirit, to the opening and infinite future. Thus gifted, Man is the only being capable of reaching towards a knowledge of himself, of nature, or of God. He is, hence, the only being capable of conscious obedience or disobedience of any moral law, the only one subject to degradation through excesses of appetite and violation of moral law, the only one with the will and power to make nature's forces his means of progress.

Man shows his exalted nature in his material structure. His fore-limbs are not made for locomotion, as in all quadrupeds. They are removed from the *locomotive* to the *cephalic* series, where they normally belong; for the fore-limbs in Vertebrates have been shown to be strictly appendages of the occipital part of the head, although far displaced in all excepting Fishes. They are fitted to serve the head, and especially the intellect and soul. Man stands erect, his body placed wholly under the brain, to which it is subservient; and his feet are simply for support and locomotion, and not, as in the Monkeys, grasping or prehensile organs for climbing. His whole outer being, in these and other ways, shows forth the divine feature of the inner being. And nature acknowledges with an appearance of homage the spiritual element of the new age; for the fierce tribes that attend Man have but one-fourth the size in bulk of those that possessed the earth in the Age of Mammals, and all her departments are full of wealth and beauty for Man's good.

1. Rock-deposits.

Stratified deposits of rock-material are in progress in the Age of Man, as they had been in the preceding ages. They occur as *alluvial* beds along the rivers; as *lacustrine* in and about lakes; as *sea-border* in beaches, sand-flats, shore-marshes, and off-shore accumulations of earth, mud, or sand; and they often contain buried shells, bones, leaves,—relics of the living species of the age. Rivers, and, about some heights, glaciers, are at work wearing down mountain-ridges and bearing the detritus to the lower lands. Icebergs, laden with earth and stones, are floated from the Arctic to the banks of Newfoundland, where they melt and drop the stony material over the bottom. Marshes over many parts of the continents have their accumulations of vegetable debris making peat, closely imitating the formation of the great beds of vegetable debris of the Coal era. The nature and origin of these modern deposits are considered under Dynamical Geology.

The peculiarity of the age, as respects its rock-deposits, allying it to Cenozoic time, and especially to the Post-tertiary, and distinguishing it from earlier ages, is the fact that its marine deposits are almost wholly confined to the borders of the continents, the deposits of the interior being, with a few small exceptions, of terrestrial or fresh-water origin.

2. Life.

The Life of the age has the following among its characteristics:—

1. There is a vast diversity of *terrestrial* life. For the continents have now their greatest extent and their greatest variety of climates; and hence, as life is adapted to all its different conditions, this life must exceed *in diversity* that of earlier time, especially that of all periods before the Post-tertiary. As to Birds and Insects, it probably exceeds greatly any earlier period in *number of species*, but not so as to Mammals and Reptiles. In *oceanic* life the age may be far behind the preceding ages, both in the *number of species* of most classes and in the *number of individuals* under the species.

2. While the Post-tertiary species of Invertebrates and Plants are the same as now exist, it cannot be asserted that all now living then existed. It is probable that, as the Post-tertiary period drew to its close, and the present climates of the globe were introduced by the movements of the earth's crust in the following Terrace epoch (p. 228), there were large additions of species, especially of those adapted to promote Man's physical, intellectual, and moral progress, through their nutritious or healing virtues, their strength and beauty, and their power of multiplying the necessities of labor and the evils of indolence.

3. The peculiar Mammalian life of the age appears to have commenced its existence mostly in the Terrace epoch, as is proved by the fact that their remains are found in

ancient alluyium in the same latitudes of Europe in which they now occur, or even in lower latitudes. For this shows that the species were distributed over the continent very much as they are now, and therefore that the climate of Europe was essentially the same as now; and this was true as the Terrace epoch made progress, and not before it in the Champlain epoch (p. 234).

4. The Mammals of the age have not more than one-fourth the bulk of those of the Post-tertiary, the *Elephants*, *Lions*, *Tigers*, *Elk*, *Deer*, *Horses*, *Sloths*, *Kangaroos*, *Beavers*, etc., being all of much reduced size.

5. When the Mammals of the age first appeared, there were still some of the great Post-tertiary Mammals in existence,—as the *Elephant*, *Rhinoceros*, *Cave-Bear*, and some others,—as is proved by the bones of these species occurring in the same beds with those of modern animals.

The cooling climate of the progressing Terrace epoch may have occasioned the final extermination of the giant Post-tertiary animals.

6. Man, the dominant species of the age, adds a new class of fossils to the earth's deposits. There are, besides his own bones, remains of his works, as, for example, flint arrow-heads and hatchets, carved wood, coins, books or parchments, buried cities like Pompeii and Nineveh.

Figure 358 represents a fossil skeleton of Man from a shell-rock of Guadaloupe. It is the remains of an Indian killed in battle two centuries since; and the rock is of the same kind with that which is now forming and consolidating on the shores. Figure 359 represents a *coin-conglomerate* containing silver coins of the reign of Edward I., found at a depth of ten feet below the bed of the river Dove in England.

7. Man appears to have begun his existence in the Terrace epoch, before the complete extinction of the Post-tertiary Mammals; for flint arrow-heads and some other human

relics are found in deposits and caverns containing bones of the same Post-tertiary species that are mentioned in § 5, as near Abbeville and Amiens in France, and at a few other localities in Europe and in Britain.

8. Man is of one species. He stands alone at the summit of the system of life.

He was created in the temperate zone,—for the species degenerates in the tropics; and in the warmer part of the

Figs. 358, 359.

Human skeleton from Guadaloupe.

Conglomerate containing coins.

temperate, because this would best suit his primitive condition, without arts or education.

His place of origin was not on both the Occidental and Oriental continents; for no species of Mammals (excepting some in the Arctic) are common to the two; but in the *Orient*, which was the continent of the highest of Mammals through the Age of Mammals, and which thereby promised to take the lead in future progress. No place of origin better accords with the conditions requisite for the species in its original state and for the commencement of its development than that region in western Asia, which is a central point of radiation for the three great Oriental lands, Asia, Europe, and Africa, where the Bible places his creation.

9. Some species of animals have become extinct since the Age of Man began, and through Man's agency. The *Dodo*, a large bird looking like an overgrown chicken in its plumage and wings, was abundant in the island of Mauritius until early in the commencement of the eighteenth century. The *Moa*, or *Dinornis*, is a New Zealand bird of the Ostrich kind that was living less than a century since; it was 10 or 12 feet in height, and the tibia (" drumstick") 30 to 32 inches long. In Madagascar remains of a still larger bird, but of similar character, occur, called an *Æpiornis;* its egg is over a foot (13½ inches) long. These are a few of the examples of the modern extinction of species.

The progress of civilization tends to restrict forests and forest-life to narrower and narrower limits. The Buffalo once roamed over North America to the Atlantic, but now lives only on the Rocky Mountain slopes west of the Missouri River. The Beaver formerly ranged over the United States from the Pacific to the Atlantic, as well as to the Arctic, and many of their remains occur in caverns near Carlisle in Pennsylvania. It is now rarely seen east of the Missouri River, though occasionally met with in northern New York and in some parts of the Appalachians to the southwest. The beaver, wolf, bear, and wild-boar were formerly common in Britain, but are now wholly exterminated.

3. Changes of Level.

The earth in this Age of Man—its ages of progress past—has beyond question reached an era of comparative repose. Its rocks are essentially completed; its mountains are made; its great outlines, early defined. have been filled out with their various details; and, now that the system of life is finished in the last creation, Man, the Earth, Man's residence, is also in its finished state. But yet not only is the formation of rocks still in progress,—the forces of nature continuing to work as in former ages,—but there are also changes of level going on of the same kind with those of past time.

These changes of level are either *paroxysmal*,—that is, take place through a sudden movement of the earth's crust as sometimes happens in connection with an earthquake; or they are *secular*,—that is, result from a gradual movement prolonged through many years or centuries. The following are some examples:—

1. *Paroxysmal*.—In 1822, the coast of western South America for 1200 miles along by Concepcion and Valparaiso was shaken by an earthquake, and it has been estimated that the coast near Valparaiso was raised at the time 3 or 4 feet. In 1835, during another earthquake in the same region, there was an elevation, it is stated, of 4 or 5 feet at Talcahuano, which was reduced after a while to 2 or 3 feet. In 1819 there was an earthquake about the Delta of the Indus, and simultaneously an area of 2000 square miles, in which the fort and village of Sindree were situated, sunk so as to become an inland sea, with the tops of the houses just out of water; and another region parallel with the sunken area, 50 miles long and in some parts 10 broad, was raised 10 feet above the delta. These few examples all happened within an interval of sixteen years. They show that the earth is still far from absolute quiet, even in this its finished state.

2. *Secular*.—Along the coasts of Sweden and Finland on the Baltic there is evidence that a gradual rising of the land is in slow progress. Marks placed along the rocks by the Swedish government, many years since, show that the change is slight at Stockholm, but increases northward, and

is felt even at the North Cape, 1000 miles from Stockholm. At Uddevalla the rate of elevation is equivalent to 3 or 4 feet in a century.

In Greenland, for 600 miles from Disco Bay, near 69° N., to the firth of Igaliko 60° 43′ N., a slow sinking has been going on for at least four centuries. Islands along the coast, and old buildings, have been submerged. The Moravian settlers have had to put down new poles for their boats, and the old ones stand "as silent witnesses of the change."

It is suspected that a sinking is also in progress along the coast of New Jersey, Long Island, and Martha's Vineyard, and a rising in different parts of the coast-region between Labrador and the Bay of Fundy. There are deeply buried stumps of forest-trees along the seashore plains of New Jersey, whose condition can hardly be otherwise explained.

The above cases illustrate movements by the century, or those slow oscillations which have taken place through the geological ages, raising and sinking the continents, or at least changing the water-line along the land.

This fact is to be noted, that these secular movements of the Age of Man are, so far as observed, *high-latitude oscillations*, just as they were in the Post-tertiary period; and they indicate, therefore, that the Post-tertiary system of changes has not yet reached its final end.

GENERAL OBSERVATIONS ON GEOLOGICAL HISTORY.

1. LENGTH OF GEOLOGICAL TIME.

By employing as data the relative thickness of the formations of the Geological ages, estimates have been made of the *time-ratios* of those ages, or their *relative* lengths (pp. 145, 198). These estimated time-ratios for the Paleozoic, Mesozoic, and Cenozoic are 14 : 4 : 3, equivalent to 3½ : 1 : ¾; —that is, Paleozoic time was 3½ times as long as the Mesozoic, and the Cenozoic was three-fourths as long. But the numbers may be much altered when the facts on which they are based are more correctly ascertained. There is no doubt that the Paleozoic era exceeded the Mesozoic in length 3 or 4 times, and probably was full twice as long as the Mesozoic and Cenozoic united. It is also quite certain that the first of the Paleozoic ages—the Silurian—was at the least three times as long as either the Devonian or Carboniferous.

Hence comes the striking conclusion that the longest age of the world since life began was the earliest,—when the earth was even without fishes and numbered in its population only Radiates, Mollusks, and marine Articulates. And the time of the earth's beginnings before the introduction of life may have exceeded in length all subsequent time.

The *actual* lengths of these ages it is not possible to determine even approximately. All that Geology can claim to do is to prove the general proposition that *Time is long.*

One of the means of calculation which have been appealed to is that afforded by the Falls of Niagara. The river below the Falls flows northward in a deep gorge, or valley, with high rocky walls, for seven miles to Lake Erie. It is reasonably assumed that the gorge has been cut out by the river, for the river is annually making progress of this very kind. From certain fossiliferous Post-tertiary beds over the country bordering the present walls, it is proved that the present gorge, about six miles long, was not made before the Glacial epoch. The present annual progress of the gorge from the cutting and undermining action of the waters has been variously estimated from *three feet a century* to *one foot a year.* At the larger estimate of one foot a year, the six miles would have required 31,000 years; and if the estimate be one inch a year, or 8⅓ feet a century, the time becomes nearly 380.000 years. Since one foot a year is proved by observation to be altogether too large an estimate, the calculation may be regarded as at least establishing the proposition that *Time is long*, although it affords no satisfactory numbers.

Other modes of calculation fully establish this general proposition. Some estimates which have been recently made seem to show that it is true even of the Age of Man; but they are based on too imperfect a knowledge of facts to be of value.

2. GEOGRAPHICAL PROGRESS IN NORTH AMERICA.

The principal steps of progress in the continent of North America are here recapitulated :—

1. The continent at the close of the Azoic lay spread out mostly beneath the ocean (map, p. 73). Although thus submerged, its outline was nearly the same as now. The dry land lay mostly to the north, as shown in the map. The form of the main mass approximated to that of the letter V, and it had a southeast and a southwest border nearly parallel to its present outline.

2. Through the Paleozoic ages, as the successive periods passed, the dry land gradually extended itself southward in consequence of a gradual elevation: that is, the sea-border at the close of the Lower Silurian was as far south as the Mohawk valley in New York; at the close of the Upper Silurian it extended along not far from the north end of Cayuga Lake and Lake Erie; and by the close of the Devonian age the State was a portion of the dry land nearly to its southern boundary. This progress southward of the sea-border in New York may be taken as an example of what occurred along the borders of the Azoic to the westward. In other words, there was through the Silurian and Devonian ages a gradual *southerly* extension of the dry part of the continent,—that is, to the southeastward and the southwestward.

By the close of the Carboniferous age, or before the opening of the Mesozoic era, the dry portion appears to have so far extended southwardly as to include nearly all the area *east* of the Mississippi and north of the Gulf States, along with a part of that *west* of the Mississippi, as far nearly as the western boundary of Kansas.

3. Before the Silurian age began, and in its first period, great subsidences were in progress along the Lake Superior region, when the thick Huronian and Potsdam formations were made. The facts show that the depression of the lake, and probably that of some of the other great lakes, and also that of the river St. Lawrence, began to form either during the closing part of the Azoic age or in the early part of the Silurian age.

4. During the Paleozoic ages, rock-formations were in progress over large parts of the submerged portions of the continent up to the sea-borders, and some vast accumulations of sand were made as drifts or dunes over the flat shores and reefs. These rock-formations had in general ten times the thickness along the Appalachian region which they had over the interior of the continent; and they were mostly *fragmental deposits* in the former region, while mostly *limestones* in the latter. Hence two important conclusions follow :—

First. The Appalachian region was through much of the time an exposed shore-reef or flat of great extent, parallel in course with the present sea-border as well as that of the ancient Azoic; while the interior was a shallow sea opening southward freely into the Gulf of Mexico, and only during some few of the periods with the same freedom eastward directly into the Atlantic. Most of the western part of the sea (west of Missouri) appears to have been too deep for deposits between the Lower Silurian and Carboniferous eras.

Secondly. The Appalachian region was undergoing, through the Silurian and Devonian ages, great changes of level, and the amount of subsidence involved exceeded by ten times that in the Interior Continental region.

5. Of this Appalachian region, some or all of the Green Mountain portion was elevated above the ocean's level at the close of the Lower Silurian; and at the same time the valley of Lake Champlain and Hudson River was formed or began.

This valley and the depressions of the Great Lakes, and also those of the lakes extending in a line through British America northwestward from Lake Superior to the Arctic, lie not far from the borders of the Azoic continent, and, therefore, between the portion of the continent that was comparatively stable dry land from the time of the Azoic onward, and that portion which was receiving rock-formations and undergoing oscillations of level. To this they owe their origin.

6. As the Paleozoic era closed, an epoch of revolution occurred, in which the rocks of the *Appalachian* region and those of the *Eastern border* underwent—(1) great changes of level; (2) extensive flexures or foldings; (3) immense faultings in some parts; (4) consolidation, and, in the eastern half especially, crystallization or metamorphism on a grand scale, and the loss of bitumen by the coal-beds changing them into *anthracite*. These changes affected the region from Labrador to Alabama. The effects of heat and uplift were more decided toward the Atlantic than toward the interior, showing that the force producing the great results was exerted in a direction from the Atlantic inland, or from the southeast toward the northwest. The Appalachian Mountains were then made; and they were, consequently, in existence when the Mesozoic era opened.

These mountains are parallel to the eastern outline of the original Azoic continent. The outline of the New York Azoic peninsula is repeated in the trend of the Appalachian chain along through western New England and Pennsylvania (the direction in New England being nearly north and south and in Pennsylvania as nearly east and west), and it is again repeated in the eastern and southern coasts of New England.

Similar changes may have taken place on the Pacific side; but facts proving this have not yet been collected.

The epoch of revolution was equally revolutionary in Europe. No living species are known to have survived from the Paleozoic into the Mesozoic.

7. In the early or middle Mesozoic period (the continent being largely dry land, as stated in the latter part of § 2), long depressions in the surface of the continent, made in the course of the Appalachian revolution and situated between the Appalachians and the sea-border, were brackish-water estuaries, or were occupied by fresh-water marshes and streams; and Mesozoic sandstone, shale, and coal-beds were formed in them. The Connecticut valley region of Mesozoic rocks (p. 164) is one example. At the same time there were formations in progress over the Rocky Mountain region, a vast area from which the sea was not excluded, or only in part: the shores of this Mesozoic interior sea appear to have extended through Kansas near the meridian of 20° west of Washington (97° west of Greenwich).

8. In the later Mesozoic, or the Cretaceous period, the continent had its Atlantic and Gulf border yet under water, and Cretaceous rocks were formed about them, and thus the continent continued its former course of enlargement southeastward (see map, p. 196). The *Western Interior* sea, opening south into the Gulf of Mexico, just alluded to, still existed, and deposits were made in it over a very large part of the great region reaching from Kansas on the east to the Colorado on the west. The Pacific border was also receiving an extension like the Atlantic.

9. In the early Cenozoic, or Tertiary period, the extension of the Atlantic and Pacific borders was still continued.

With its close the progress of the continent in rock-making southeastward and southwestward was very nearly completed.

The *Western Interior* sea had become greatly contracted after the Cretaceous period by the elevation of the Rocky Mountain region; and, although the Mexican Gulf still remained of more than twice its present area, it was much reduced in size (map, p. 217). At the beginning of the Tertiary period the Ohio and Mississippi reached an arm of the Gulf just where they join their waters; at its close the Ohio had taken a secondary place as a tributary of the Mississippi. The great Missouri River, the real trunk of the Interior river-system rather than the Mississippi, began its existence after the Cretaceous period, and reached its full size only towards the close of the Tertiary, when the Rocky Mountains had finally attained their full height.

10. The elevation of the Rocky Mountains, like that of the Appalachians, was the raising of the land along a region *parallel* with the outline of the original Azoic continent (see map, p. 73). The elevation of the Cascade range of Oregon and Sierra Nevada of California was a doubling of this same line on the west; while the elevation of the trap ridges and red sandstone of the early Mesozoic along the Atlantic border (p. 165) was a doubling of the line on the east.

11. The continent being thus far completed, as the Post-tertiary period was drawing on, operations changed from those causing southern extension to those producing movements of ice and fresh waters over the land, especially in the higher latitudes; and thereby valleys, great and small, were excavated over the continent; earth and gravel were transported and made to cover deeply the rocks and spread the continent with fertile plains and hills; and, as the final result, those grand features and those qualities of surface

were educed that were requisite to make the sphere a fit residence for Man.

3. PROGRESS OF LIFE.

From the survey of the Life of the globe which has been made, the following conclusions may be drawn. Future discovery may change some of the details; but it is not probable that it will affect the general principles announced.

1. *Fact of progress of life.*—Life commenced among plants in *Sea-weeds;* and it ended in *Palms*, *Oaks*, *Elms*, the *Orange*, *Rose*, etc. It commenced among animals in *Lingulæ* (Mollusks standing on a stem like a plant) and in *Crinoids* and *Trilobites*, if not earlier in the simple systemless *Protozoans* (p. 58); it ended in *Man.* Sea-weeds were followed by Ferns and other *Flowerless* plants, and by *Gymnosperms*, the lowest of *Flowering* plants; these finally by the higher *Flowering* species above mentioned,—the *Palms* and *Angiosperms. Radiates*, *Mollusks*, and *Articulates* of the Silurian afterwards had *Fishes* associated with them; later, *Reptiles;* later, *Birds* and *inferior Mammals;* later, *higher Mammals*, as *Beasts of prey* and *Cattle;* lastly, *Man.*

2. *Progress from marine to terrestrial life.*—The Silurian and Devonian were eminently the *marine* ages of the world. The plants of the Silurian are sea-weeds, and the animals all marine. The animals of the Devonian, also, are mainly marine; but there is a step taken in terrestrial life by the introduction of land-plants and Insects.

In the Carboniferous age and through the Mesozoic era the continents, or large areas over them, underwent alternations between a submerged state and dry land, leading a kind of amphibian existence. The Carboniferous age had, besides aquatic life and Insects, its terrestrial Mollusks and Centipedes, its Amphibian and other Reptiles, besides a great profusion of forest-trees and other terrestrial vegetation. In the early Mesozoic, to Reptiles were added Birds and Mammals, eminently terrestrial kinds of life.

The Cenozoic was distinctively a continental era. The continents became mostly dry land after its earliest epoch; and as the Age of Man approached, they had their full size and their present diversities of surface and climate. With the increased variety of conditions fitted for terrestrial life there was, beyond question, a great augmentation in the number and variety of terrestrial species. Mammals were most numerous in kinds in the Post-tertiary; but Birds and Insects have probably their greatest numbers and variety of species in the present age. Marine species still abound, but relatively to the terrestrial they are far less numerous and less extensively distributed than in the Mesozoic and earlier ages.

3. *Progress was connected with a constant change of life by exterminations and the introduction of new species.*—No species of animal survived from the beginning of life on the globe to the present time, nor even through a single one of the several geölogical ages; and but few lived on from the beginning of any one of the many periods to its close, or from one period to another.

There were universal exterminations, according to the existing state of testimony (with perhaps an exception as regards some species of oceanic life, p. 203), closing some of the ages, as the Carboniferous and the Reptilian; there were exterminations, nearly as complete, closing the periods on each of the continents; and others, usually less complete, closing epochs; and often some exterminations accompanying each change in the rock-depositions that were in progress. For, in passing from one bed to another above, some fossils fail that occur below; and from the strata of one epoch to another, still larger proportions disappear; and sometimes with the transitions to rocks of another period or age, all the species are different.

Of all genera of animals now having living species, only *two* (and those Molluscan, *Lingula* and *Discina*) commenced their existence in the earliest Silurian; every other genus of that early time sooner or later numbered only extinct species.

Such unbroken lines prove the oneness of plan or system through geological history, and, therefore, of purpose in the Creator.

Five hundred species of Trilobite lived in the course of the Paleozoic ages: afterward there were none. 900 species of the Ammonite group existed in the Mesozoic, —not all at once, but, as in the case of the Trilobites, in a succession of genera and species: the last then disappeared. There have been 450 species of the Nautilus tribe in existence: now there are but 2 or 3, and these are peculiar to the present age. 700 species of Ganoids have been found fossil: the tribe is now nearly extinct. The remains of 2500 species of plants and nearly 40,000 species of animals have been found in the rocks, not one of which is now in existence. These are a few examples of the extinctions of tribes that have taken place. But the number of kinds of *fossils* discovered cannot be the number of species that have existed; and the above numbers of marine species may safely be multiplied by *three*, and of terrestrial by *twenty*.

The facts show that the life of the world underwent constant changes through exterminations and creations.

4. *Progress not always begun by the introduction first of the lowest species of a group.*—Mosses, although inferior to Ferns, appear to have been of later introduction, for no remains have been found in the Carboniferous or Devonian rocks, in which rocks there are relics of both Ferns and Gymnosperms.

The earliest of Fishes, instead of being those of lowest grade, were among the highest: they were Ganoids, or reptilian Fishes (that is, a kind intermediate in some respects between Fishes and Reptiles), along with others of the order of Selachians or Sharks, the superior division of the class. Trilobites of the first fauna of the Silurian are not the lowest of Crustaceans. No fossil Snakes have been found below the Cenozoic, although large Reptiles abounded in the Mesozoic. Oxen date from the later Tertiary, long after the first appearance of many higher Mammals, as *Tigers*, *Dogs*, *Monkeys*, etc.

There was upward progress in the grand series of species, as stated in § 1, but there was not progress in all cases from the lowest species to the highest.

5. *The earliest species of a group were often those of a comprehensive type.*—The *Ganoid* fishes are an example of these *comprehensive* types. As stated on page 111, they were *intermediate* between Fishes and Reptiles; they were fishes *comprehending* in their structure some Reptilian characters, and hence called *comprehensive* types.

The Selachians are another example of a comprehensive type; for the sharks have some important peculiarities in which they approximate to the higher Vertebrates and even Mammals, as is seen in their mode of development and in the very small number of their young.

Fishes commenced with these two comprehensive types, —the *Ganoid* and *Selachian*.

The earliest Mammals were *Marsupials*, or species of Mammals comprehending in their structure some characteristics of *oviparous* Mammals (see p. 50), and, therefore, in certain respects intermediate between Mammals and Oviparous Vertebrates.

The vegetation of the coal era included trees allied to the small Ground-pine or Lycopodia of the present day; and these, as well as the Lycopodia, constitute a type intermediate in some points between Ferns and Pines or Conifers (p. 108). There were at the same time Sigillariæ,—a type allied closely to the Pine tribe, but intermediate between it and the Lycopodia and Ferns.

In the Mesozoic the most characteristic plants were Cycads; and these comprehended in their structure something of *three* distinct types. They are most closely like Conifers in fruit; but they are like Ferns in the way the leaves unfold, and in some other points, and like Palms in their habit of growth and their foliage (p. 167).

These comprehensive types embraced in their natures usually the features of some type that was to appear in the future. Thus, the Ganoid fishes of the Devonian in a sense foreshadowed the type of Reptiles, the species under which did not come into existence until long afterward in the Carboniferous age. The Cycads in a similar manner foreshadowed the Palms, a type which did not appear until the Cretaceous period.

6. *Harmony in the life of a period or age.*—Through the existence of these *comprehensive* types, and also in other ways, there was always a striking degree of harmony between the species making up the population—or the fauna and flora—of each period in the world's history.

Among the plants of the Carboniferous age there were—(1) the highest of the Cryptogams, or Flowerless plants, the Ferns; (2) the lowest of Phenogams (Gymnosperms), or Flowering plants, species having only inconspicuous and imperfect flowers, and hence *almost flowerless;* and (3) the *intermediate* types of Lycopodia (Lepidodendra) and Sigillariæ.

Again, in the Mesozoic the terrestrial Vertebrate life included—(1) Reptiles, which are *oviparous* species; (2) Birds, also *oviparous* species; (3) reptilian Birds, having long tails like the Reptiles, a comprehensive type; (4) Insectivorous (Insect-eating) Mammals; (5) *semi-oviparous* Mammals, or Marsupials, an intermediate type between the true Insectivores and the *oviparous* Reptiles and Birds.

This kind of harmony existed in all the ages.

It exists none the less now when the types have their widest diversity; for the less size of the brute beasts than in the Post-tertiary, remarked upon on page 239, and the reference throughout the Flora and Fauna of the world to Man, are in full harmony with the spiritual being at the head of the existing creation.

7. *Progress always the gradual unfolding of a system—Man the culmination of that system.*—There were higher and lower species created through all the ages, but the successive populations were still, in their general range, of higher and higher grade; and thus the progress was ever upward. The type or plan of vegetation, and the four grand types or plans of animal life (the Radiate, Molluscan, Articulate, and Vertebrate), ordained in the act of creation, were each displayed under multitudes of tribes and species, rising in rank with the progress of time, and all under relations so harmonious and so systematic in their successions that they seem like the expression—in material living forms—of one divine idea.

With every new fauna and flora in the passing periods, there was a fuller and higher exhibition of the kingdoms of life. Had progress ceased with the Post-tertiary, when the world was given up to brute passion and ferocity, the system might have been pronounced the scheme of an evil demon. But, as time moved on, Man came forth,—not in strength of body, but in the majesty of his spirit; and then living nature was full of beneficence. The system of life, about to disappear as a thing of the past, had its final purpose fulfilled in the creation of a spiritual being,—one having powers to search into the depths of nature and use the wealth of the world for his physical, intellectual, and moral advancement, that he might thereby prepare, under divine aid, for the new life in the coming future.

Thus, through the creation of Man completing the system of life, all parts of that system became mutually consistent and full of meaning, and Time was made to exhibit its true relation to Eternity.

Methods of exterminations of species and extinctions of tribes.—(1.) Some species of plants and animals require dry land for their support and growth; some, fresh-water marshes or lakes; some, brackish water; some, seashore or shallow marine waters; some, deeper ocean-waters.

Hence, (*a*) movements in the earth's crust submerging large continental areas, or raising them from the condition of a sea-bottom to dry land, would exterminate life:—sinking them in the ocean, extinguishing *terrestrial* life, raising them from the ocean, extinguishing *marine* life. In early times, when the continental surface was in general nearly flat, a change of level of a few hundred feet, or perhaps of even 100, would have been sufficient for a wide extermination. If a modern coral island were to be raised 150 feet, its reef-forming corals would all be killed; or if sunk in the ocean 150 feet, the same result would follow,—because the species do not grow below a depth of 100 feet. And if all the coral-reefs of the Pacific were simultaneously sunk or raised to the extent stated, there would be a total extinction of a large number of species.

(*b*) Along a seacoast the bays and inlets sometimes are closed by barriers thrown up by the sea, and hence become fresh, killing all marine life. Again, barriers are often washed away by the sea, and then salt water enters, destroying *fresh-water* life.

(2.) Species are also made for a limited range of temperatures: some, for the equatorial regions only; some, for the cooler part of the tropical zone; some, for the warmer temperate latitudes; some, for the middle temperate; some, for the colder temperate; some, for the frigid zone; and few species live through two such zones.

Hence, (*a*) as the earth has gradually cooled in its climates from a time of universal tropics to that of the present condition, those tribes or families made for the earlier condition of the globe afterward became of necessity extinct. This may be a reason why many of the tribes of the ancient world disappeared, and why the Reptilian type culminated in the Mesozoic; these species were made especially for the warm condition which then prevailed.

Again, (*b*) any temporary change of climate over the globe—from cold to warm or warm to cold—would have exterminated species. An increase in the extent and height of Arctic lands would have increased the cold, as shown by Lyell, and thereby sent cold winds south over the continents and cold oceanic currents south along the border of the oceans.

On the contrary, a diminution in the extent of Arctic lands, making the higher regions open seas, or an increase in the extent of tropical lands for the sun to heat, would have increased the heat of the globe and sent a warm climate far north.

Such changes are destructive to living species. It is suggested on p. 204 that the destruction of life at the close of the Mesozoic may have arisen from the cause here explained.

(3.) The heat which has escaped from the earth's interior through the crust, in connection with igneous eruptions, or seasons of metamorphic changes when the earth's rocks were crystallizing on a vast scale, would have caused a destruction of all marine life in the vicinity; and where metamorphic action has taken place through an area a thousand miles or more in length, as in the progress of the Appalachian revolution (p. 155), the devastation must have extended over a large part of the continental area.

Origination of species.—Geology affords no support to the hypothesis that species have been made from pre-existing species, and suggests no theory of development by natural causes. In other words, it has no facts sustaining the notion that *Man* was made through the gradual progress or improvement of some one of the *Apes*, or by any method of development out of an *Ape*, or that *Elephants* were so made from *Mastodons*, or the reverse, or from any other species, or one species of *Monkey*, *Cat*, *Horse*, etc., from another; and much less does it favor the hypothesis that the whole system of animal life is nothing but a growth from one, two, or more original species, one changing into, or evolving, another, through a method of development, as supposed in a *development-hypothesis*. The facts the science has thus far collected prove that a system of life has been gradually brought out in the course of the ages. But it gives no information, in the author's opinion, as to the manner in which the Divine will called into existence the successive tribes or species.

The science in its present state affords the following evidence bearing on this subject:—

1. Species do not shade into one another as if they had originated by transitions from one another. For example, the Post-tertiary *Mastodon* and *Elephant* of North America do not pass into one another or into other earlier species; or the *Apes* into the species *Man;* or any *Mollusks* or *Articulates*, through a series of stages, into *Fishes;* or any *Seaweeds* into *Ferns* or the earliest land-plants, etc. The species of plants and animals at the present day as well as those of the past, with comparatively few exceptions, have their limits well defined, and do not blend with one another by insensible gradations.

2. Groups commence sometimes in their higher species. Thus, Fishes—the earliest of Vertebrates—began with the *Ganoids* and *Sharks*, with no evidence of a progress upward from lower species. The first of Land-plants are the *Ferns*,

Lepidodendra, etc.; and no species of the inferior group of *Mosses* have been found marking a line of progress upward to the *Lepidodendra*. Many other such cases might be mentioned.

3. The earth's progress has involved the occurrence at intervals of revolutions or devastations. Some of these devastations appear to have been nearly or quite universal over the globe, while others have been confined to single continents, or limited areas, and have been only partial (see p. 162). But, whether universal or not, they have often cut off short not only *species*, but *genera*, *families*, and *tribes;* and yet the same genera, families, and tribes have had new species afterwards. Life has been re-introduced where it had been exterminated, as if the system were not at the mercy of temporary catastrophes, but owed its restoration and continued progress to a power that was independent of all causes of desolation and could even use desolation as a means of progress.

The advocates of a development-hypothesis do not deny the above evidence; but they argue that the records are very imperfect, full of long breaks; and, again, that only a small part of the world has been searched for its truths, and that part not thoroughly.

But a hypothesis unsustained by facts just where it would be most natural to look for them, and resting for its geological basis on possible discoveries in the future, may well be left to pass as a mere suggestion until the discoveries have been made. This is the dictate of true Science.

Geology has no theory of creation to present; and its discoveries are already so extensive, and so corroborative of the general results arrived at, from whatever continent they have been gathered, that its present silence is in weighty opposition to such views. The science testifies to the fact that plants and animals have come into existence in a long succession of species. It demonstrates the oneness in plan and purpose of all nature, and thereby the oneness of its Author. It points to boundless wisdom in every step of progress, and with increasing distinctness as the era approaches when Man should appear and receive the Divine command, "Subdue and have dominion." But it directs to no cause of the origin of species but the Cause of causes, —the infinite God.

In the account of creation given in the first chapter of Genesis, it is stated that on the *fifth* day the waters brought forth abundantly the moving creature that hath life, the flying creatures of the air, and the great whales (a word meaning as truly reptiles). In the commencing Silurian the first appearance of the swarming life of the waters took place (p. 93). In the Devonian, Fishes and Insects were added; in the Carboniferous, Reptile life began; and in the Mesozoic, Birds as well as Reptiles existed, and the latter became the dominant life of the globe. At the same time, small semi-oviparous Mammals, or Marsupials, with probably some Insectivores, appeared as precursors of the age that was next to follow. With the close of the Mesozoic the Reptile world ended; and so ended also the fifth day of the Mosaic record.

On the *sixth* day there were two great works,—first, the creation of Mammals, and, as a second, the creation of Man.

With the opening Cenozoic, Mammals came forth in great numbers and of large size; and as the era advanced, they increased in variety until the type reached an expansion as to magnitude of individuals and numbers of kinds even exceeding the exhibition of it in the present age. Thus passed the first portion of the sixth day. Finally Man appeared as the last great work.

Creation finished, the day of rest followed,—the era of the finished world, the era also of Man's progress and preparation for another and a higher life. And as the "six days" work of creation is succeeded by a seventh of rest, so, it has been well said, the Sabbath closes man's week, as a day of rest and of preparation for that spiritual life.

PART IV.

DYNAMICAL GEOLOGY.

DYNAMICAL GEOLOGY treats of the *causes* or *origin* of events in Geological history,—that is, of the *origin* of rocks, —of disturbances of the earth's strata, and their effects, —of valleys,—of mountains,—of continents,—and of the changes in the earth's features, climates, and living species.

The agencies of most importance, next to the universal power of *Gravitation*, are *Life*, the *Atmosphere*, *Water*, *Heat*, and *Cohesive* and *Chemical* attraction.

The following are the subdivisions of the subject here adopted:—1. Life; 2. The Atmosphere; 3. Water; 4. Heat —the mechanical effects of the Atmosphere, Water, and Heat being considered under these heads; 5. Movements in the earth's crust, and their consequences, including the folding and uplifting of strata, the production of earthquakes, and the origin of mountains and of the earth's general features. Chemical Geology, which treats of the chemical operations connected with the origin of rocks, constitutes another division of the subject, but is not here taken up.

I. LIFE.

Life has done much geological work by *contributing material* for the making of rocks. Nearly all the limestones of the globe, all the coal, and some siliceous beds, besides portions of rocks of other kinds, have been formed out of the stony relics of living species.

Through simple growth and the power of secretion, *Vertebrates* form a bony skeleton; *Mollusks* make shells, which are calcareous, or nearly of the composition of common limestone; *Polyps* make Corals, also calcareous; *Crinoids* make stems and flower-like skeletons that are calcareous; and the Polyps and Crinoids, although as really animal as any quadruped, are yet so low in organization that nine-tenths of the bulk of the animal are often stony (calcareous), and still the functions of life are perfectly carried on.

There are various kinds, also, of microscopic species which contribute to the material of rocks. The *Rhizopods* among animals (p. 59) make calcareous shells, each containing one or many minute cells; the *Diatoms* among microscopic plants (p. 61) make siliceous shells; the *Polycystines* among microscopic animals make siliceous shells.

Plants also make beds of coal and peat out of accumulations of leaves and stems, as already in part explained on page 135.

In further illustration of this subject, three examples of rock-making may be described:—1. Peat-formations; 2. Beds of microscopic organisms; 3. Coral-reefs.

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1. Peat-formations.

Peat is an accumulation of half-decomposed vegetable matter formed in wet or swampy places. In temperate climates it is due mainly to the growth of mosses of the genus *Sphagnum*. These mosses form a loose turf; and, as they have the property of dying at the extremities of the roots while increasing above, they may gradually form a bed of great thickness. The roots and leaves of other plants, or their branches and stumps, and any other vegetation present, may contribute to the accumulating bed. The carcasses and excrements of dead animals at times become included. Dust may also be blown over the marsh by the winds.

In wet parts of Alpine regions there are various flowering plants which grow in the form of a close turf, and give rise to beds of peat like the moss. In Fuegia, although not south of the parallel of 56°, there are large marshes of such Alpine plants, the mean temperature being about 40° F.

The dead and wet vegetable mass slowly undergoes a change, becoming an imperfect coal, of a brownish-black color, loose in texture, and often friable, although commonly penetrated with rootlets. In the change the woody fibre loses a part of its gases; but, unlike coal, it still contains usually 25 to 33 per cent. of oxygen. Occasionally it is nearly a true coal.

Peat-beds cover large surfaces of some countries, and occasionally have a thickness of forty feet. One-tenth of Ireland is covered by them; and one of the "mosses" of the Shannon is stated to be fifty miles long and two or three broad. A marsh near the mouth of the Loire is described by Blavier as more than fifty leagues in circumference. Over many parts of New England and other portions of North America there are extensive beds. The amount in Massachusetts alone has been estimated to exceed 120,000,000 of cords. Many of the marshes were originally ponds or shallow lakes, and gradually became swamps as the water, from some cause, diminished in depth. The peat is often underlaid by a bed of whitish shell marl, consisting of fresh-water shells—mostly species of *Cyclas* and *Planorbis*—which were living in the lake. There are often also beds of the siliceous shields of Diatoms.

Peat is used for fuel and also as a fertilizer. When prepared for burning, it is cut into large blocks and dried in the sun. It is sometimes pressed in order to serve as fuel for steam-engines. *Muck* is another name of peat, and is used especially when the material is employed as a manure; but it includes also impure varieties not fit for burning, being applied to any black swamp-earth consisting largely of decomposed vegetable matter.

Peat-beds sometimes contain standing trees, and entire skeletons of animals that had sunk in the swamp. The peat-waters have often an antiseptic power, and flesh is sometimes changed by the burial into adipocere.

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2. Beds of Microscopic Organisms.

Microscopic life abounds in almost all waters, especially over muddy bottoms,—as in lakes, rivers, marshes, salt-water swamps, harbors, bays, the shallow borders of the ocean, and also the deep ocean. Part of the species make no stony secretions, but much the larger part form calcareous or siliceous shells. Although these shells are, with few exceptions, exceedingly minute, the most part wholly invisible unless highly magnified, they are in so vast numbers in many places, and multiply so rapidly, that they form in time thick beds out of their accumulated shells. A square yard covered with these microscopic species will increase upward not only as fast as a square yard of an oyster-bank, but much more rapidly, because of their extreme simplicity of structure, their rapid reproduction, and the fact that nearly the whole bulk of each one is in stony material.

The *calcareous* species, or *Rhizopods*, abound in the shallower waters along the borders of the ocean, and also over its bottom where thousands of feet deep. Over what is called the *Telegraphic plateau*, between Ireland and Newfoundland, they appear to make a nearly continuous bed for a thousand miles or more in breadth, and perhaps more than this from north to south. The thickness of the great limestone-formation there in progress, out of these minute shells, is of course unknown. The genera of shallow water are mostly different from those of the deep sea.

The *siliceous* species are either *Diatoms* or *Polycystines*. They occur both in shallow and deep waters, like the Rhizopods. The Diatoms are found in cold as well as warm seas, and in fresh waters as well as marine. Over the bottoms of shallow lakes they make thick beds, just as the Rhizopods do in the ocean; and many of the peat-beds rest on a thick layer of Diatoms made from species that were living in the lake that afterwards became the peat-growing swamp.

The rock made of Rhizopod shells is exemplified in chalk, —a soft white or whitish limestone. That consisting of Diatoms often looks like a very fine whitish earth; but it is sometimes compacted into a nearly solid mass, and sometimes into an imperfect slate.

On p. 192 it is stated that the flint which occurs in chalk may have been made from the silica of Diatoms and of the spicula of sponges.

These are examples of beds formed by simple growth and multiplication of living species. The shells are in size like the grains of a fine powder; and it is only necessary that they be consolidated as they lie, in order that a compact rock shall be made out of the accumulation.

3. Coral-Reefs.

In tropical regions corals grow in vast plantations about most oceanic islands and the shores of the continents. The greatest depth at which the reef-making species live is about 100 feet; and from this depth to sometimes a foot above low-tide level, they flourish well. The patches or groves of coral are usually distributed among larger areas of coral sand, like small groves of trees or shrubbery in some sandy plains.

The corals have much resemblance to vegetation in their forms and their modes of growth; and the animals are so like flowers in shape and bright colors that they are called *flower-animals* (p. 57). Along with the corals there are also great numbers of *Shells*, besides *Crabs*, *Echini*, and other kinds of marine life.

The coral plantations are swept by the waves, and with great force when the seas are driven by storms. The corals are thus frequently broken, and the fragments washed about until they are either worn to sand by the friction of piece upon piece, or become buried in the holes among the growing corals, or are washed up the beach. Corals are not injured by mere breaking, any more than is vegetation by the clipping of a branch, and those that are not torn up from the very base and reduced to fragments continue to grow.

The fragments and sand made by the waves, and by the same means strewed over the bottom along with the shells also of Mollusks, commence the formation of a bed of coral-rock,—literally a bed of limestone, for the coral and shells have the composition of limestone. As the corals continue growing over this bed, fragments and sand are constantly forming, and the bed of limestone thus increases in thickness. In this manner it goes on increasing until it reaches the level of low tide; beyond this it rises but little, because corals cannot grow wholly out of water, and the waves have too great force at this level to allow of their holding their places, if they were able to stand the hot and drying sun. The bed of calcareous rock thus produced is a *coral-reef*.

Since reef-corals grow to a depth of only 100 feet, the thickness of the reef cannot much exceed 100 feet if the sea-bottom remains at a constant level, except where there are oceanic currents to transport to greater depths the sand that is made. But should the reef-region be slowly sinking at a rate not faster than the corals can grow and make the reef rise, then almost any thickness may be made. From observations about the coral regions of the Pacific, it is supposed that some of the reefs have a thickness of two or three thousand feet or more, which has been acquired during such a slow subsidence.

The coral formations of the Pacific are sometimes broad reefs around hilly or mountainous islands, as shown in the annexed sketch. To the left in the sketch there is an inner

Fig. 360.

View of a high island, bordered by coral-reefs.

reef and an outer reef, separated by a channel of water, the inner of which (*f*) is called a *fringing* reef, and the outer (*b*) a *barrier* reef. They are united in one beneath the water. At intervals there are usually openings through the barrier reef, as at *h*, *h*, which are entrances to harbors. The channels are sometimes deep enough for ships to pass from harbor to harbor.

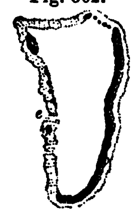
Many other coral-reefs stand alone in the ocean, far from any other lands. The latter are called *coral islands*, or *atolls*.

Fig. 361.

Coral island, or Atoll.

They usually consist of a narrow reef encircling a salt-water lake. The lake is but a patch of ocean enclosed by the reef and its groves of palms and other tropical plants. When there are deep openings through the reef, ships may enter the lake, or *lagoon*, as it is usually called, and find excellent anchorage. The annexed figure (fig. 362) is a map of one of the atolls of the Kingsmill Islands in the Pacific. The reef on one side—the windward—is wooded throughout; but on the other it has only a few wooded islets, the rest being bare and partly washed by the tides. At *e* there is an opening to the lagoon.

Fig. 362.



Apia, of the Kingsmill group.

The Paumotu archipelago, just northeast of the Society Islands, contains between 70 and 80 coral islands; the Carolines, with the Radack, Ralick, and Kingsmill groups on their eastern border, as many more; and others are scattered over the intervening ocean. Most of the high islands between the parallels of 28° north and south of the equator, and also the borders of the continents, have their fringe of coral-reefs, unless (1) the waters adjoining the coasts are too deep, or (2) the bottom is too muddy, or (3) the mouths of rivers are in the vicinity to pour in fresh waters, which are injurious to corals, or (4) cold oceanic currents sweep the coasts. Corals are limited by the parallel of 28°, because they will not flourish where the mean temperature of the coldest winter month is below 68° F.

The limestone beds made from corals and shells are not a result of growth alone, as in the case of the deposits formed from microscopic organisms, but of growth *in connection with the breaking and wearing action of the ocean's waves and currents.* Corals and shells, unaided, could make only an open mass full of large holes, and not a solid rock. There must be sand or fine fragments at hand, such as the waters can and do constantly make in such regions, in order to fill up the spaces or interstices between the corals or shells. If there is clayey or ordinary siliceous sand at hand, this will suffice, but it will not make a *pure* limestone; in order to have the rock a proper limestone, the shells and corals must be the source of the sand or fine fragments, for these alone yield the needed calcareous material and cement. The limestone made in this way by the help of the waves may be, and often is, as fine-grained as a piece of flint or any ordinary limestone. In other cases it contains some imbedded fragments in the solid bed; in others it is a coral conglomerate; and over still other large areas it is a mass of standing corals with the interstices filled in solid with the sand and fragments. In some regions the compact coral limestone is an oolite (p. 25).

The pages on the results of microscopic life have explained one method by which the ancient limestones of the globe have been made. The process of limestone-making now going on through the agency of coral animals illustrates another method, and far the most common. The beds, in the case of these limestones, are a result of the slow growth of living corals, crinoids, shells, and the like, and the gradual wearing of the calcareous remains more or less completely to sand and pebbles, preparatory for consolidation.

The extent of some of the modern reefs matches nearly that of some of the Paleozoic reefs. On the north of the Feejee Islands the reef-grounds are 5 to 15 miles in width. In New Caledonia they extend 150 miles north of the island and 50 miles south, making a total length of 400 miles. Along northeastern Australia they stretch on, although with many interruptions, for 1000 miles. The modern reef-grounds, although often of great length, are, however, narrow, unlike those of the early geological ages. But this difference arises from the fact that the regions giving the requisite depth for abundant Coral and Molluscan life are now of narrow limits, being confined to the borders of the continents, whereas in ancient time the continents were to a large extent submerged at shallow depths and afforded the conditions requisite for immense Coral, Crinoidal, and Molluscan plantations.

II. THE ATMOSPHERE.

The following are some of the mechanical effects connected with the movements of the atmosphere.

1. *Destructive effects from the transportation of sand, dust, etc.* —The streets of most cities, as well as the roads of the country, in a dry summer day, afford examples of the drift of dust by the winds. The dust is borne most abundantly in the direction of the prevalent winds, and may in the course of time make deep beds. The dust that finds its way through the windows into a neglected room indicates what may be done in the progress of centuries where circumstances are more favorable.

The moving sands of a desert or seacoast are the more important examples of this kind of action.

On seashores, where there is a sea-beach, the loose sands composing it are driven inland by the winds into parallel ridges higher than the beach, forming *drift-sand hills.* They are grouped somewhat irregularly, owing to the course of the wind among them, and also to little inequalities of compactness or to protection from vegetation. They form especially (1) where the sand is almost purely siliceous, and therefore not at all adhesive even when wet, and not good for giving root to grasses; and (2) on windward coasts. They are common on the windward side, and especially the projecting points, even of a coral island, but never occur on the leeward side, unless this side is the windward during some portion of the year. On the north side of Oahu they are thirty feet high and made of coral sand. Some of them, which stand still higher (owing to an elevation of the island), have been solidified, and they show, where cut through, that they consist of thin layers lapping over one another; and they evince also, by the abrupt changes of direction in the layers (see fig. 17 *f*), that the growing hill was often cut partly down or through by storms, and again and again completed itself after such disasters.

This style of lamination and irregularity is characteristic of the drift-sand hills of all coasts. On the southern shore of Long Island there are series of sand-hills of the kind described, extending along for one hundred miles, and five to thirty feet high. They are partially anchored by straggling tufts of grass. The coast of New Jersey down to the Chesapeake is similarly fronted by sand-hills. In Norfolk, England, between Hunstanton and Weybourne, the sand-hills are fifty to sixty feet high.

2. *Additions to land by means of drift-sands.*—The drift-sand hills are a means of recovering lands from the sea. The appearance of a bank at the water's surface off an estuary at the mouth of a stream is followed by the formation of a beach, and then the raising of hills of sand by the winds, which enlarge till they sometimes close up the estuary, exclude the tides, and thus aid in the recovery of the land by the depositions of river-detritus. Lyell observes that at Yarmouth, England, thousands of acres of cultivated land have thus been gained from a former estuary. In all such results the action of the waves in first forming the beach is a very important part of the whole.

3. *Destructive effects of drift-sands—Dunes.*—Dunes are regions of loose drift-sand near the sea. In Norfolk, England, between Hunstanton and Weybourne, the drift-sands have travelled inland with great destructive effects, burying farms and houses. They reach, however, but a few miles from the coast-line, and were it not that the sea-shore itself is being undermined by the waves, and is thus moving landward, the effects would soon reach their limit.

In the desert latitudes, drift-sands are more extended in their effects.

4. *Sand-scratches.*—The sands carried by the winds, when passing over rocks, sometimes wear them smooth, or cover the surface with scratches and furrows, as observed by Wm. P. Blake over granite rocks at the Pass of San Bernardino in California. Even quartz was polished, and garnets were left projecting upon pedicels of feldspar. Limestone was so much worn as to look as if the surface had been removed by solution. Glass in the windows of houses on Cape Cod sometimes has holes worn through it by the same means.

III. WATER.

The subject of Water is here considered under the following heads:—

1. Fresh Waters; including especially Rivers and the smaller Lakes, and also *subterranean* as well as *superficial* waters.
2. The Ocean; including, along with the ocean, the larger Lakes, whether salt or fresh.
3. Frozen Waters, or Glaciers and Icebergs.

1. FRESH WATERS.

A. SUPERFICIAL WATERS, OR RIVERS.

The mechanical effects of fresh waters are—

1. Erosion, or wear.
2. Transportation of earth, gravel, stones, etc.
3. Distribution of the transported material, and formation of fragmental deposits.

1. Erosion.

The waters of rivers descend in the form of rain and snow from the clouds, and are derived by evaporation both from the surface of the land, with its lakes, rivers, and foliage, and from the ocean, but mostly from the latter. The waters rise into the upper regions of the atmosphere, and, becoming condensed into drops or snow-flakes, fall over the hills and plains. They gather first into rills; these, as they descend, unite into rivulets; these, again, if the region is elevated or mountainous, into torrents; torrents, flowing down the different mountain valleys, combine with other torrents to form rivers; and rivers from one mountain-chain sometimes join the rivers from another and make a common stream of great magnitude, like the Mississippi or the Amazon.

The Mississippi has its tributaries among all the central heights of the Great Rocky Mountain chain, throughout a distance of 1000 miles, or between the parallels of 35° N. and 50° N.; and still another set of tributaries gather in waters from the Appalachian chain, between western New York and Alabama. Rills, rivulets, torrents, and rivers combine over an area of millions of square miles to make the great central trunk of the North American continent.

The amount of water poured each year into the ocean by the Mississippi averages 19½ trillions (19,500,000,000,000) cubic feet, varying from 11 trillions in dry years to 27 trillions in wet years. This amount is about *one-quarter* of that furnished by the rains, the rest being lost mostly by direct evaporation, but also in part by absorption into the soil and by contributing to the growth of vegetation.

Erosion, or wear, goes on wherever the waters have motion. The rain-drop makes an impression (fig. 21) where it falls; the rill and rivulet carry off light sand and deepen their bed, as may be seen on any sand-bank or by many a roadside; torrents work with far greater power, tearing up rocks and trees as they plunge along, and, in the course of time, making deep gorges or valleys in the mountain-slopes; and rivers, especially in periods of flood, hurry on with vast power, making wider valleys over the breadth of a continent.

The slopes of a lofty mountain, exposed through ages to the action described, finally become reduced to a series of valleys and ridges, and the summit often to towering peaks and crested heights,—all these effects originating in the fall of rain-drops or snow-flakes.

The tendency of many rocks to decompose, aids the waters in producing their mechanical effects.

Where the stream has a rapid descent, and is therefore a torrent, it plunges on with great violence and erodes mainly along its bottom. Lower down the mountain, where the slope of its bed is gentle, it becomes more quiet, and excavates but slightly, if at all, at bottom. In its floods, however, it spreads beyond its banks and tears away the earth or rocks, encroaching on the hills either side, and making for itself a broad flat, or *flood-plain.* As the floods cease, the stream becomes again confined to its channel. Every river has thus its *channel* for the dry season, and its *flood-plain* which it covers in times of overflowing.

The great rivers of the continents, as well as the streamlets along roadsides, illustrate this subject. Wherever, in countries that have rain, there is a ridge, be it small or large, there are gullies, or gorges, or valleys; and if any of its streams are followed up to their head, there will be found, first, the *channel* and its bordering *flood-plain;* then the narrower valley with the hurrying torrent, receiving smaller torrents along its course; then, towards the top, the torrent dwindling to a rivulet, or, if the summit is nearly flat and wooded, there may be at top wet swampy land or lakes.

A cascade usually occurs on a rapid stream, where in the course of it there is a hard bed of rock overlying a soft one. The hard bed resists wear, while the soft one below yields easily: thus a plunge begins, which increases in force as it increases in extent. The rills and rivulets made by a shower of rain along roadsides or sand-banks often illustrate also this feature of the great mountain streams.

When the rocks underlying a region are nearly horizontal, the valleys cut by the rivers have usually bold rocky sides. In many parts of the Rocky Mountains the streams have worked their way down through the rocks for hundreds, and at times even thousands, of feet. Such a place is often called a cañon (pronounced as if spelled canyōn).

These cañons are of wonderful magnitude and depth on the Colorado River, over the west slope of the Rocky Mountains, between longitude 111° W. and 115° W. For

Fig. 363.

Cañon of the Colorado near its junction with Green River.

300 miles there is a continuous cañon, 3000 to 6000 feet deep. The annexed sketch, furnished the author by Dr.

Newberry (the Geologist of the Expedition, under Lieutenant J. C. Ives, that surveyed this region and first made known the facts), represents the great plain of the Colorado region, with its deep vertical cuts opening down to running water. This water is the Colorado River, and the opening that looks so much like a mere crack in the rocks has a depth at the place of about 3000 feet. The deep gorge is the result, as stated by Dr. Newberry, of erosion by the stream, which is still continuing its wearing action. The isolated flat-topped hills and turreted rocks in the distance are portions of strata that once covered the other rocks, being all of the upper formations that the eroding waters have left.

The rocky gorge, 7 miles long and 200 to 250 feet deep, in which the Niagara River flows in violent rapids after its plunge at the great fall, is believed with reason to have been made by the waters, and mainly through the action of the plunging stream at the fall. Every year rocks are undermined and tumbled down into the depths below, and thus the position of the fall is slowly changing, moving higher and higher up stream with the successive years. The rock, for half the height of the fall, or 80 feet, is of hard limestone; but the lower half is of soft shale, and, being easily worn away by the waters, it undermines the limestone and thus assists in the movement.

2. Transportation by rivers, and distribution of transported material.

1. *Fact of transportation.*—It has been stated that the massive mountains have been eroded into valleys and ridges by running water. The material worn out has been transported *somewhere* by the same waters.

Part of the transported material in all such operations goes to form the great alluvial plains that occupy the river-valleys throughout their course. Part is carried on to the sea into which the river empties, when it meets the counteracting waves and currents and is distributed for the most part along the shores, filling estuaries or bays, or making deltas, and extending the bounds of the land.

Thus the mountains of a continent are ever on the move seaward, and contribute to the enlargement of the seashore plains. The continent is losing annually in mean height, but gaining in width or extent of dry land.

2. *The transporting power of water.*—The transporting power of running water is very great when the flow is rapid. Doubling the rate of flow increases *sixty-four* times the force of the water. Large stones and masses of rocks are torn up and moved onward by the mountain-torrent; pebbles, when the current runs but a few miles per hour; and at slower rates, gravel, sand, or, when very slow, only fine clay. Hence, as a stream loses in rapidity of movement, it leaves behind the coarser material, and carries only the finer; if the rate becomes very slow, it drops the gravel or the sand, and bears on only the finest earth or clay.

Consequently, where the current is swift, the bottom (and the shores also wherever the current strikes them) is stony or pebbly; and where the water is still, or nearly so, the bottom and shores are muddy.

The larger part of the transportation by rivers is done in their seasons of flood. Then it is that streams are muddy with the earth they are bearing along.

3. *Wearing action on the transported material.*—The stones are not only transported by the waters, but by the mutual friction thus produced they are made into rounded stones and reduced to pebbles and earth. Nearly all the rounded stones, gravel, and earth of fields and gardens over the globe, and also the material of all geological formations, has been made out of pre-existing solid rocks by the wearing action of waters,—either those of streams over the land, or those of the ocean.

The finer transported material is called *detritus* (from the Latin for *worn out*), and also *silt*. The rounded stones are termed *boulders*.

4. *Amount of material transported.*—The amount of transported material varies with the size and current of the rivers and the kind of country they flow through. The Mississippi carries to the Gulf of Mexico, according to Humphreys & Abbot, annually, on an average, 812,500,000,000 pounds of silt,—equal to a mass one square mile in area and 241 feet deep,—and its bottom-waters push on enough more to make the 241 feet 268 feet. The total annual discharge of silt by the Ganges has been estimated at 6.368,000,000 cubic feet.

5. *Alluvial formations.*—The deposits made by the transported material which now constitute the alluvial plains of the river-valleys cover a very large part of a continent, since rivers or smaller streams are almost everywhere at work. They are made up of layers of pebbles or gravel, and of earth, silt, or clay, especially of these finer materials. Some logs, leaves, and bones occur in them; but these are rare; for whatever floats down stream is widely scattered by the waters, and to a great extent destroyed by wear and decay.

6. *Estuary and delta formations.*—The detritus-material discharged by the river at its mouth tends to fill up the bay into which it empties, and make wide flats on its borders, and thus contract it to the breadth merely of the river-current.

Where the tides are feeble and the river large, the deposits about the mouth of the stream gradually encroach on the ocean, and make great plains and marshy flats, which are intersected by the many mouths of the river and a network of cross-channels. Such a formation is called a *delta.* Figure 364 represents the *delta* of the Mississippi, the white lines being the water-channels, and the black the great alluvial plains. The delta properly commences below the mouth of Red River, where the Atchafalaya *bayou*, or side-channel of the river, begins. The whole area is about 12,300 square

Fig. 364.

Delta of the Mississippi.

miles; about one-third is a sea-marsh, only two-thirds lying above the level of the Gulf.

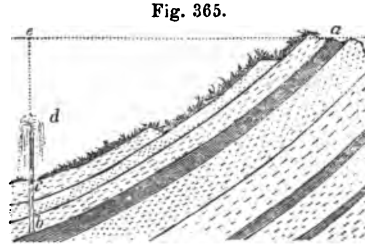
The deltas of the Nile, Ganges, and Amazon are similar in general features to that of the Mississippi.

The detritus poured into the ocean where the tides or currents are strong, and a considerable part of that where the tides are feeble, goes to form seashore flats and sand-banks and off-shore deposits. In their formation the ocean takes part through its waves and currents; and hence they are more conveniently described in connection with the remarks on oceanic action.

B. SUBTERRANEAN WATERS.

1. *Origin and course of subterranean waters.*—A part of the waters that fall on the earth's surface—on its mountains as well as its plains—sinks through the ground and often penetrates to unknown depths between the strata or their layers. Such under-ground waters become under-ground streams; and, as their channels are surrounded by rocks, the water flows actually in a tube. When, therefore, they have their source in elevated regions, the pressure increases with the descent, and wherever an opening in the country below gives them a chance of escape, they often come out with great force. By boring down through the rocks, such an under-ground stream may be struck in almost any region, and frequently the water will rise and rush out of the opening in a jet of great height.

Fig. 365.



Section illustrating the origin of Artesian wells.

In fig. 365 the under-ground waters are supposed to enter at *a*, along a clayey layer (for clayey layers hold the water, while it will soak through a sandy one); it escapes by the boring *b c*, and is thrown up in a jet to *d*. There is so much friction along the bed of the stream in the course of its descent, that the height of the jet is always much less than the whole descent, or *b e*.

Such wells are usually called *Artesian wells* or *borings*, from the district of Artois in France, where they were early made. The Artesian well of Grenelle in Paris is 2000 feet deep. One at St. Louis has a depth of 2200 feet; another at Louisville is over 2000 feet. Such wells are used for agricultural purposes in California, and for manufacturing in various cities, as New York, New Haven, etc.

The under-ground waters often gush out along a seashore, or from beneath the sea; and sometimes in so great volume that vessels at certain seasons are enabled to take in fresh water from alongside while lying off in a harbor.

They flow and have cascades in many caverns, as in the Mammoth Cave, Kentucky, the Adelberg Cave near Trieste in Austria, and many others. In some cases they come out to the surface in sufficient volume to turn a mill, and are set to work immediately on their showing themselves.

2. *Erosion.*—Subterranean waters have eroding and transporting power, as well as those of the land, and may excavate large channels.

3. *Land-slides.*—*Land-slides* are of different kinds:—

(1.) The sliding of the surface earth or gravel of a hill down to the plain below. This effect may be caused by the waters of a severe storm wetting the material deeply and giving it *greatly increased weight*, besides loosening its attachment to the more solid mass below.

(2.) The sliding down a declivity to the plain below of the upper layer of a rock-formation. This may happen when this upper layer rests on a clayey or sandy layer and the latter becomes very wet and greatly softened by the waters; the upper layer slides down on the softened bed.

(3.) The settling of the ground over a large area. This may take place when a layer of clay or loose sand becomes wet and softened by percolating waters, and then is pressed out laterally by the weight of the superincumbent layers.

But this effect cannot be produced unless there happens to be a chance for the wet layer to move or escape laterally.

2. THE OCEAN.

The ocean is vast in extent and vast in the power which it may exert. But its mechanical work in Geology is mostly confined to its coasts and to soundings, where alone material exists in quantity within reach of the waves or currents. In ancient time, when the continents were nearly flat and to a great extent submerged at shallow depths, this work was performed simultaneously over a large part of their surface, and strata nearly of continental extent were sometimes formed. In the present age, oceanic action is confined to the borders of the continents.

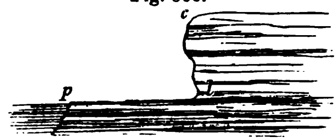
The mechanical effects of the ocean are produced by its waves and currents.

1. Erosion and Transportation.

1. **Waves.**—(1.) *General action.*—The *oceanic waves* are a constant force. Night and day, year in and year out, with hardly an intermission, they break against the beaches and rocks of the coasts;—sometimes gently, sometimes in heavy plunges that have the force of a Niagara of almost unlimited breadth. The gentlest movements have some grinding action on the sands, while the heaviest may dislodge and move along up the shores rocks many tons in weight. Niagara wastes its power by falling into an abyss of waters: while in the case of the waves the rocks are bared anew for each successive plunge. Cliffs are undermined, rocks are worn to pebbles and sand, and sand ground to the finest powder. Rocky headlands on windward coasts are especially exposed to wear, since they are open to the battering force from different directions.

(2.) *Level of greatest eroding action.*—The eroding action is greatest for a short distance above the height of half-tide, and, except in violent storms, it is almost null below low-tide level. Figure 366 represents in profile a cliff, having its lower layers, near the level of low-tide, extending out as a platform a hundred yards wide. As the tide commences to move in, the waters while still quiet swell over and cover this platform, and so give it their protection; and the force of wave-action, which is greatest above half-tide, is mainly expended near the base of the cliff, just above the level of the platform.

Fig. 366.



Cliff, New South Wales.

(3.) *Action landward.*—Waves on shallow soundings have some transporting power; and, as they always move toward the land, their action is landward. They thus beat back, little by little, any detritus in the waters, preventing that loss to continents or islands which would take place if it were carried out to sea.

(4.) *Effect on outline of coasts—No excavation of narrow valleys.*—As the action of waves on a coast tends to wear away headlands, and at the same time to fill up bays with detritus, the general result will be to render the outline more regular or even. There is nowhere a tendency to excavate narrow valleys into a coast, like those occupied by rivers. Such valleys are made by the waters of the land; for the ocean can work at valley-making only when it has already an open channel for the waters to pass through, and then the valleys are of very great width. If a continent were sinking slowly in the ocean, or rising slowly from it, wave-action would still be attended by the same results; for each part of the surface would be successively a coast-line, and over each there would be the same wearing away of headlands and filling of bays, instead of the excavation of valleys.

2. **Tidal currents.**—*Tidal currents* often have great strength when the tide moves through channels or among islands, and consequently are a means of erosion and transportation in daily action wherever there is mud or sand within their reach, as is usually the case in the vicinity of the land.

The *out-flowing* current, or that connected with the ebbing tide, is deeper in its action and has, therefore, more excavating and more transporting power than the *in-flowing*, or that of the incoming tide. The latter moves on as a great swelling wave, and fills the bays much above their natural level; but the out-flowing current begins along the bottom in bays before the tide is wholly in, owing to the accumulation of waters, and when the tide changes it adds to the strong current-movement already in progress.

The piling up of the waters in a bay by the tides, or by storms, produces, especially if the entrance is not very broad, a strong out-flowing current at bottom, which tends to keep the channel deep and clear of obstructions.

The *bore* or *eagre* of some great rivers is a kind of tidal flow up a stream. It is produced when the regular rise of the tide in the bay at the mouth of the river is prevented by the form of the entrance and its sand-banks, together with the outflow of the river, so that the waters are for a while prevented from entering until, finally, all of one tide rush in at once, or in a few great waves. The *eagres* of the Amazon, the Hoogly in India (one of the mouths of the Ganges), and the Tsien-tang in China, are among the most remarkable. In the case of the Tsien-tang, the water moves up stream in one great wave, plunging like an advancing cataract, 4 or 5 miles broad and 30 feet high, at a rate of 25 miles an hour. The boats in the middle of the stream simply rise and fall with the passage of the wave, being pushed forward only a short distance; but along the shores there is great devastation, the banks being worn away and animals often surprised and destroyed.

3. **Currents made by winds.**—There are also *currents produced by winds*, especially when there are long storms, or when the winds blow for months in one direction. The currents thus made have but little depth. Sweeping by an island, they transport from one place to another in their course more or less of the sand of the shores, and the same sand may be in part carried back again when the season changes to that in which the wind blows from the opposite direction. Other portions of detritus may be carried by them away from the island and distributed in the deeper waters.

4. **Great oceanic currents.**—The *great currents of the ocean*, like that called the *Gulf Stream*, are for the most part so distant from the borders of the continents that little detritus comes within their reach. As these currents have great depth,—often a thousand feet or more,—their course is determined by the deep-water slopes of the submerged border of a continent, so that when the submerged border is shallow for a long distance out (as off New Jersey and Virginia, where this long distance is even 50 to 80 miles), the current is equally remote, and exerts very feeble if any action near the shores. Wherever it actually sweeps close along a coast, it will bear away some detritus to drop it over the bottom in the neighboring waters.

The oceanic currents flowing from polar seas produce important effects by means of the icebergs which they bear into warmer latitudes. These icebergs are freighted with thousands of tons of earth and stones; and wherever they melt, they drop the whole to the ocean's bottom. The sea about the Newfoundland banks is one of the regions of the melting bergs; and there is no doubt that vast submarine unstratified accumulations of such material have been there made by this means. It has been suggested that the banks may have been thus formed.

2. Distribution of material, and the formation of marine and fluvio-marine deposits.

1. **Origin of material.**—The material used by the waves and currents is either—(1) the stones, gravel, sand, or earth produced by the wear of coasts; or (2) the detritus brought down by rivers and poured into the ocean, as explained on page 281.

The latter in the present age is vastly the most important. But in the earlier geological ages, when the dry land was of very small extent, rivers were small and were but a feeble agency. The ocean had then vastly greater advantages than now, because, as stated on page 84, the continents were mostly submerged at very shallow depths, or lay near tide-level within reach of the waves and currents.

2. **Forces in action.**—In the distribution of this material, the waves and marine currents may work alone, in the manner explained on the preceding pages, or in conjunction with river-currents wherever these exist.

3. **Marine formations.**—The marine formations are of the following kinds:—

(1.) *Beach-accumulations.*—Beaches are made of the material borne up the shores by the waves and tides and left above tide-level. This material consists of stones or pebbles, sand, mud, earth, or clay. It is *coarse* when the waves break heavily, because, although trituration to powder is going on at all times, the powerful wave-action and the undercurrent carry off the finer material into the off-shore shallow waters, where it settles over the bottom or is distributed by currents. It is *fine* where the waves are gentle in movement, as in sheltered bays, the triturated material remaining in such places near where it is made, and often being the finest of mud.

(2.) *Sand-banks, or reefs—Shallow-water accumulations.*—Shallow-water accumulations may be produced in bays, estuaries, or the inner channels of a coast, and over the bottom outside. They consist usually of coarse or fine sand and earthy detritus, but may include pebbles or stones when the currents are strong. The material constituting them is derived from the land through the triturating and transporting action of the waves and currents. The accumulations may increase under wave-action in shallow water, until they approach or rise above low-tide level, and then they form sand-banks. Such sand-banks keep their place in the face of the waves, for the same reason as the platform of rock mentioned on page 284 and illustrated in fig. 366.

(3.) *Fluvio-marine formations.*—Most of the accumulations in progress on existing shores, whether sand-banks, or estuary or off-shore deposits, especially about well-watered continents, contain more or less of river-detritus, and are modified in their forms by the action of river-currents. Along the whole eastern coast of the United States south of New England, and on all the borders of the Gulf of Mexico, the formations in progress are mainly *fluvio-marine*,—that is, the combined result of rivers and the ocean. The coast-region on the continent is now slowly widening through this means, and has been widening for an indefinite period. This coast-region is low, flat, often marshy, full of channels or sounds; and facing the ocean there is a barrier reef, made of sand.

The rivers pour out their detritus especially during their floods, and the ocean's waves and currents meet it as the tide sets in with a counter-action, or one from the seaward; and between the two the waters lose in rate of flow and drop the detritus over the bottom. When the river is very large and the tides feeble, the banks and reefs extend far out to sea. The Mississippi thus stretches its many-branched mouth (p. 280) many miles into the Gulf. When the tide is high, sand-bars are formed; and the higher the tides the closer are the sand-bars to the coast. When the stream is small, the ocean may throw a sand-bank quite across its mouth, so that there shall be no egress to the river-waters except by percolation through the sand; or, if a channel be left open, it may be only a shallow one.

3. Structure of the formations.

Beach-formations are very irregular in stratification. The layers—as shown in figure 17*e*, page 31—have but little lateral extent, and change in character every few feet. They often include patches of stones, as well as pebbles and sand.

The *sand-banks* and *reefs* made along a coast have much more regular stratification, and are mostly composed of sand with some beds of pebbles. They often vary much every mile or every few miles.

Those beds that are *formed in shallow waters*, as in bays or in the off-shore waters, retain a uniformity of stratification over much larger areas, and may consist of pebbles, sand, or finer earth. The extent and regularity of level of the submerged area will determine in a great degree the extent to which the uniformity of stratification may extend; and in this respect the former geological ages, as observed on page 287, had greatly the advantage of the present.

Ripple-marks (figure 18, p. 32) are made by the spread of the waters in a wave up a beach, or by wave-action on the bottom within soundings where the depth does not exceed 60 or 80 fathoms. *Rill-marks* (fig. 19) are produced when the return waters of a tide, or of a wave that has broken on a beach, flow by an obstacle, as a shell or pebble, and are piled up a little by it so as to be made to plunge over it and so erode the sands for a short distance below the obstacle. The *oblique lamination* in a layer, or *ebb-and-flow* structure, results from the rapid inward movement of the tide, or of a current, over a sandy bottom: it makes a series of inclined layers by the piling action; when the movement ceases, the detritus will deposit horizontally for a while; and afterward the same inward movement may be repeated, producing anew the *oblique lamination.*

The imbedded shells and other animal relics in a beach are worn or broken; those in the bays or off-shore shallow waters out of the reach of the waves may be unbroken, or may lie as they did when living; but if the waters are not so deep but that the shells or corals are exposed to wave-action, they may be broken or worn to powder, and enter in this state into the formation in progress. See (page 85) the remarks on the formation of limestone from shells or corals. In the sands of beaches near low-tide level, borings of Sea-worms, or of some Mollusks or Crustaceans, may exist.

3. FREEZING AND FROZEN WATERS.

A. FREEZING WATER.

As water in the act of freezing expands, the freezing process, when taking place in the seams of rock, opens the seams and tears masses asunder. This kind of action is especially destructive in the case of rocks that are much fissured, or intersected by joints, or that have a slaty or laminated structure. As the action continues through successive years and centuries, it may result in great accumulations of broken stone. The slope, or *talus*, of fragments at the foot of bluffs of trap or basalt is often half as high as the bluff itself. In tropical countries, bluffs have no such masses of ruins at their base.

Granular rocks, whether crystalline or not, when they readily absorb water, lose their surface-grains by the same freezing process. Granite, as well as porous sandstones, may thus be imperceptibly turning to dust, earth, or gravel. In Alpine regions this action may be incessant.

B. FROZEN WATER.

The effects of ice and snow are conveniently considered under three heads:—1. The ice of lakes and rivers; 2. Glaciers; 3. Icebergs.

1. ICE OF LAKES AND RIVERS.

The ice of lakes and rivers often freezes about stones along their shores, making them part of the mass; and other stones sometimes fall on the surface from overhanging bluffs. In times of high-water, or floods, the ice, rising with the waters, may carry its burden high up the shores, or over the flooded flats, to leave them there as it melts; or, if within reach of the current, it may transport the stones far down stream. This is a common method of transportation by ice. Large accumulations of boulders are sometimes made by this means on the shores of lakes far above the ordinary level of the waters.

2. GLACIERS.

1. *Glaciers are ice-streams*, or rivers in which the moving material is *frozen* instead of *liquid* water.

Like large rivers, they have their sources in high mountains, derive their waters from the clouds, and descend along the valleys; but the mountains are such as take snow from the clouds instead of rain, because of their elevation. They rise only in those mountains that receive annually a large supply of snow from the clouds; for the snow must accumulate to a great depth.

Like large rivers, many tributary streams coming from the different valleys unite to make the great stream.

As with rivers, their movement is owing to gravity, or to the weight of the material; but the average rate of motion, instead of being some miles an hour, is generally but 8 to 10 inches a day, or a mile in 15 to 25 years.

As with rivers, the central portions move most rapidly, the sides and bottom being retarded by friction; but the difference of rate between the sides and bottom is far greater in glaciers than in rivers.

The snow of the mountain-tops, which is perhaps hundreds of feet deep, becomes compacted and converted into ice mainly by its own weight; and thus the *glacier* begins. As it starts on its course, the clouds furnish new snows to keep up the supply and help press on the moving mass.

2. *Fractures attending the movement—Crevasses.*—Every valley has its ridgy sides, its sharp turns, its abrupt narrowings and widenings, its irregular bottom; and the stiff ice, compelled to accommodate itself to these irregularities, has, consequently, profound *crevasses* made usually along its borders, besides multitudes of cracks that are not visible at the surface; also, still profounder chasms when wrenched in turning some point; longer crevasses, crossing even its whole breadth, when the ice plunges down a steep place in an ice-cascade, or when, on escaping from a narrow gorge, it moves off freely again with increase of slope. Again, it may lose all its crevasses, from their closing up, when the motion is impeded by diminished slope or otherwise.

3. *Descent below the snow-line.*—The icy mass thus descends 5000 to 7500 feet below the snow-line, or the limit of perpetual snow. It resists the melting heat of summer because of its mass, just like the ice in an ice-house. Though starting where all is white and barren, it passes by regions of Alpine flowers, and often continues down to a country of gardens and human dwellings before its course is finally cut short by the climate. Thus, the *Mer de Glace*, which, under the name of the *Bois Glacier*, rises in Mont Blanc and other neighboring peaks, terminates in the vale of Chamouni. And in a similar manner two great glaciers descend from the Jungfrau and other heights of the Bernese Alps to

the plains of the Grindelwald valley just south of Interlachen.

Fig. 367 represents one of the ice-streams of the Mount Rosa region in the Alps, from a view in Professor Agassiz's work on Glaciers. It shows the lofty regions of perpetual

Fig. 367.

Glacier of Zermatt, or the Görner Glacier.

snow in the distance; the bare rocky slopes that border it, later on its course; and the many crevasses that intersect the surface of the ice-stream.

4. *Glacier torrent.*—The melting over the surface of a glacier and about the sides of its crevasses gives origin to a stream of water flowing beneath it, which becomes gradually a torrent of considerable size, and finally emerges to the light from beneath the bluff of ice in which the glacier

terminates. Thence it continues on its rocky course down the valley.

5. *Method of movement.*—The movement and condition of a glacier is almost wholly dependent on the facility with which ice breaks and unites again into solid ice when the broken surfaces are brought into contact. This quality, first noticed by Faraday and applied to Glaciers by Tyndall, is called *regelation*, the word meaning *a freezing together again.* It is easily tried by breaking a lump of ice and bringing the surfaces again into contact: if moist, as they are at the ordinary temperature, they at once become firmly united. A glacier moves on and accommodates itself to its uneven bed by breaking when necessary, and in its progress it may soon become as solid as before. Thus it breaks and mends itself as it goes.

Small portions of a glacier may slide along its bed, but the glacier never slides as a whole. In some places there may be an adaptation to an uneven surface by bending without breaking (which may take place if the force be exceedingly slow in action); but this also is a means of motion of small importance, compared with the first mentioned.

6. *Transportation by Glaciers—Moraines.*—Glaciers become laden with stones and earth falling from the heights above, or coming down in crushing avalanches of snow and stones. The stones and earth make a band along either border of a glacier, and such a band is called a *moraine.* When two glaciers unite, or a tributary glacier joins another, they carry forward their bands of stones with them; but those on the uniting sides combine to make one moraine. A large glacier like that in fig. 367 may have many moraines,—or one less than the number of its tributaries. Some of the masses of rock on glaciers are of immense size. One is mentioned containing over 200,000 cubic feet,—which is equivalent in cubic contents to a building 100 feet long, 50 wide, and 40 high.

In the lower part of a glacier the several moraines lose their distinctness through the melting of the ice; for this brings to one level the dirt and stones of a considerable part of its former thickness, and the surface, therefore, becomes covered throughout with earth and stones. The bluff of ice which forms the foot of a glacier is often a dirty mass, showing little of its real nature in the distant view.

The final melting leaves all the earth and stones in unstratified heaps or deposits, to be further transported, eroded and arranged by the stream that flows from the glacier.

7. *Erosion by Glaciers.*—A glacier so laden with stones must have stones in its lower surface and sides as well as in its mass. As it moves down its valley, it consequently abrades the exposed rocks over which it passes, smoothing and polishing some surfaces, covering others closely with parallel scratches, and often ploughing out broad and deep channels, besides scratching or smoothing the ploughing boulders.

In addition to these minor operations, glaciers deepen and widen the valleys in which they move. In this work they are aided by the frosts (p. 290), avalanches, and glacier torrents.

8. *Glacier regions.*—The best known of Glacier regions are those of the Alps, in one of which Mont Blanc stands, with its summit 15,760 feet above the sea. There are glaciers also in the Pyrenees and the mountains of Norway, Spitzbergen, in the Caucasus and Himalaya, in the Southern Andes, in Greenland and other Arctic regions, etc. One of the Spitzbergen glaciers borders the coast for 11 miles with cliffs of ice 100 to 400 feet high. The great Humboldt Glacier of Greenland, north of 79° 20′, has a breadth at foot where it enters the sea of 45 miles; and this is but one glacier among many in that icy land.

3. ICEBERGS.

When a glacier like those of Greenland terminates in the sea, the icy foot bearing its moraines becomes broken off from time to time; and these fragments of glaciers, floated away by the sea, are *icebergs.* The geological effects of icebergs have been stated on page 286.

4. FORMATION OF SEDIMENTARY BEDS.

The following is a brief recapitulation of the explanations of the origin of deposits given in the preceding pages. Igneous and other crystalline rocks are not here included.

1. **Sources of material.**—The material of sedimentary rocks has come either—(1) from the degradation of pre-existing rocks, or (2) from a state of solution in the waters of the globe. These waters have in general taken up their mineral material originally from the rocks, except that part which has always existed in the ocean ever since the ocean began to be.

The principal means of degradation are the following:—1. Erosion by moving waters, either those of the sea or land (pp. 283, 273); 2. Erosion by ice, either that of glaciers, icebergs, or ordinary snow and ice (pp. 291, 295); 3. Pressure of water filtrating into fissures; 4. Freezing of water in fissures (p. 290); 5. Chemical decomposition, in the course of which rocks are crumbled down to fragments or earth.

2. **Formation of deposits.**—The methods by which deposits have been formed are the following:—

1. *By the waters of the sea.*

(1.) Through the sweep of the ocean *over the continents when barely or partly submerged,—making* (*a*) sandy or pebbly deposits near or at the surface where the waves strike, or at very shallow depths where swept by a strong current; (*b*) argillaceous or shaly deposits near or at the surface, where sheltered from the waves, and also, at considerable depths, out of material washed off the land by the waves or currents; but *not making* (*c*) coarse sandy or pebbly deposits over the deep bed of the ocean, as even great rivers carry only silt to the sea; and *not making* (*d*) argillaceous deposits over the ocean's bed except along the borders of the land, unless by the aid of a river like the Amazon, in which case, still, the detritus is mostly thrown back on the coast by the waves and currents.

(2.) Through the waves and currents of the ocean acting *on the borders of the continent* with the same results as above, except that the beds have less extent.

(3.) Through living species, and mainly Mollusks, Radiates, and Rhizopods, affording calcareous material for strata (p. 19), and Diatoms and some Protozoans, siliceous material (p. 14). All rocks made of corals, and the shells of Mollusks, excepting the smallest, require the help of the waves at least to fill up the interstices; but Rhizopods and siliceous Infusoria may make rocks in deep water, by accumulation, which are in no sense sedimentary. See pp. 265, 266.

2. *By the waters of lakes.*—Lacustrine deposits are essentially like those of the ocean in mode of origin, unless the lakes are small, when they are like those of rivers.

3. *By the running waters of the land.*—(1.) Filling the valleys with alluvium, and moving the earth from the hills over the plains (p. 277). (2.) Carrying detritus to the sea or to lakes, to make, in conjunction with the action of the sea or lake waters, delta and other seashore accumulations (p. 279).

4. *By frozen waters.*—(1.) Spreading the rocks and earth of the higher lands over the lower, and, in the process, bearing onward blocks of great size, such as cannot be moved by other means, as well as finer material (pp. 291, 294). (2.) Carrying rocks and earth from the land to the ocean, either to the seashore, making accumulations in lines or moraines,

or to distant parts of the ocean, as from the Arctic to the Newfoundland Banks; and thus contributing to deep or shallow water or shore sedimentary accumulations, distinguished for the irregular intermingling of huge blocks of stone, pebbles, and earth (p. 286).

5. GENERAL EFFECTS OF EROSION OVER CONTINENTS.

The outlining of mountain-ridges and valleys has been in part produced by subterranean forces upturning and fracturing the strata; but the final shaping of the heights is due to erosion. This cause has been in action from the earliest time, and the material of nearly all rocks not calcareous have resulted from the erosion of pre-existing formations.

The Appalachians have probably lost by denudation more material than they now contain. Mention has been made of faults of even twenty thousand feet along the course of the chain from Canada to Alabama. In such a fault, one side is left standing twenty thousand feet above the other, equivalent in height to some of the loftier mountains of the globe; and yet now the whole is so levelled off that there is no evidence of the fault in the surface-features of the country. The whole Appalachian region consists of ridges of strata isolated by long distances from others with which they were once continuous. Fig. 253 represents a common case of this kind. It is supposed by some geologists that the Appalachian and Western coal-fields were once united, and that, in western Ohio and other parts of the intermediate region, strata thousands of feet deep, from the Lower Silurian upward, have been removed, and this over a surface many scores of thousands of square miles in area. This view has been questioned on a former page. Whether true or not, there is no doubt that the anthracite coal-fields of central Pennsylvania were once a part of the great bituminous coal-field of western Pennsylvania and Virginia (fig. 219, p. 118). They are now in isolated patches, and formations of great extent have been removed over the intervening country. The Illinois coal-region is broken into many parts in consequence of similar denudation and uplifts.

In New England there is evidence of erosion on a scale of vast magnitude since the crystallization of its rocks. On the summit-level between the head-waters of the Merrimac and Connecticut, there are several pot-holes in hard granite; one, as described by Professor Hubbard, is ten feet deep and eight feet in diameter, and another is twelve feet deep. They indicate the flow of a torrent for a long age where now it is impossible; and the period may not be earlier than the Post-tertiary. Many other similar cases are described by Hitchcock.

These examples of denudation are sufficient for illustration. Europe and the other continents furnish others no less remarkable, and to an indefinite extent.

IV. HEAT.

The crust of the earth derives heat from *three* sources:—1. The sun, an external source; 2. The earth's heated interior; 3. Chemical and mechanical action. The first two sources are geologically the most important.

Internal heat.—The fact of a high heat in the earth's interior is established in various ways.

1. *The form of the earth.*—The form of the earth is a spheroid, and a spheroid of just the shape that would have resulted from the earth's revolution on its axis, provided it had passed through a state of complete fusion, or of igneous fluidity, and had slowly cooled over its exterior. Hence follows the conclusion that it has passed through such a state of fusion, which is greatly strengthened by the other evidence here given. Another conclusion also follows:—namely, that the earth's axis had the same position (or, at

least, very nearly the same) when cooling began as now. There is no evidence that there has been at any time a change.

2. *Crystalline character of the lowest rocks.*—On descending through the earth's strata, the lowest reached are crystalline rocks. The Azoic rocks, which are the earliest, have been found to be, wherever observed, either crystalline or firmly consolidated, which proves that they must have been subjected for a long time to the action of heat.

3. *Artesian borings.*—In deep borings for water, like those mentioned on page 282, it has been found that the temperature of the earth's crust increases *one degree* of Fahrenheit for every 50 or 60 feet of descent. The rate of 1° F. for 50 feet of descent, in the latitude of New York, would give heat enough to boil water at a depth of 8100 feet; and at a depth of about 28 miles the temperature would be 3000° F., or that of the fusing point of iron. Since, however, the fusing temperature of any substance increases with the pressure, the depth required before a material like iron would be found in a melted state, would be greater than this. The facts suffice at least to prove that the earth has a source of heat within, and that a very high heat exists at no great depth. If the solid crust is 100 miles thick, it is still thin compared with the distance to the earth's centre.

4. *Distribution of Volcanoes.*—The great Pacific Ocean has nearly a complete girt of volcanoes, extinct or active, and all of its many islands that are not coral are wholly volcanic islands,—excepting New Zealand and a few others of large size in its southwest corner. Volcanoes occur along many parts of the Andes from Tierra del Fuego to the Straits of Darien, in Central America, in Mexico, California, Oregon, and beyond; in the Aleutian Islands on the north; in Kamtchatka, Japan, the Philippines, New Guinea, New Hebrides, New Zealand on the west; and on Antarctic lands both south of New Zealand and South America. The volcanic

region thus bounded is equal to a whole hemisphere, and is ample proof as to the nature of the whole globe. With outlets of fire so extensively distributed over this vast area, there surely must be some universal seat of fire beneath.

But there are volcanoes also in the East Indies in great numbers, both extinct and active, in the islands of the Indian Ocean, in the West Indies, in the islands of the Atlantic, and in the vicinity of the Mediterranean and Red Seas.

The various evidences mentioned combine to prove that the interior of the earth is a source of heat.

EFFECTS OF HEAT.

The following are the effects of heat here considered:—

1. Volcanoes.
2. Igneous ejections that are not volcanic.
3. Metamorphism, and the production of mineral veins.

The heat of the globe is also one of the causes of earthquakes, of change of level in the earth's crust, and of the elevation of mountains: these subjects are considered in the following chapter. It is an important agent also in all chemical changes.

1. VOLCANOES.

A. General nature of volcanoes and their products.

Volcanoes are mountain-elevations of a somewhat conical form, which eject or have ejected at some time streams of melted rock. If the fire-mountain has at present no active fires within, and is emitting no vapors, it is said to be *extinct*. The following figure is a sketch of the lofty volcano of Cotopaxi, as published by Humboldt. The height of the peak is 18,876 feet. The larger volcanic mountains are seldom so steep as in this figure. Etna, about 10,000 feet high, and Mount Kea and Mount Loa of Hawaii, nearly 14,000 feet, have an average slope of less than 10 degrees. The form of a cone with a slope of 7 degrees—which is the average for the Hawaiian volcanoes—is shown in figs. 369, 370; fig. 369 has a pointed top, like Mount Kea, and fig. 370

Fig. 368.

Volcano of Cotopaxi.

a rounded outline, like Mount Loa, whose form is that of a very low dome

Fig. 369.

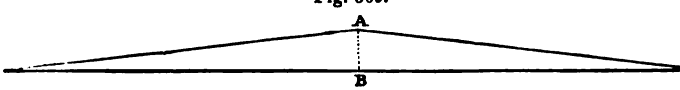
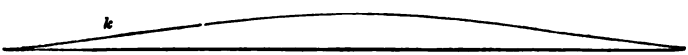


Fig. 370.



The highest of volcanic mountains on the globe are the Aconcagua peak in Chili, 23,000 feet, and Sorata and Illimani, in Bolivia, each over 24,000 feet. The former appears to be still emitting vapors, showing that the fires are not wholly extinct. The mountains *Shasta*, *Hood*, *Helens*, and others in California and Oregon are isolated volcanic cones 13,000 to 15,000 feet high.

The cavity or pit in the top of a volcanic mountain, where the lavas may often be seen in fusion, is called the *crater*. It is sometimes thousands of feet deep, but may be quite shallow; and in extinct volcanoes it is often wholly wanting, owing to its having been left filled when the fires went out.

The liquid rock issuing from a crater, and the same after becoming cold and solid, is called *lava*.

An active *crater*, even in its most quiet state, emits *vapors*. These vapors are mostly simple steam, or aqueous vapor; but in addition there are usually sulphur gases, and sometimes carbonic acid or muriatic acid.

In a time of special activity, fiery jets are sometimes thrown up to a great height, which, in the distance, at night look like a discharge of sparks from a furnace. These jets are made of red-hot fragments of the liquid lava; the fragments cool as they descend about the sides of the crater, and are then called *cinders*.

When a shower of rain, or of moisture from the condensed steam, accompanies the fall of the cinders, the result is a mud-like mass, which dries and becomes a brownish or yellowish-brown layer or stratum called *tufa*. It is often much like a soft coarse sandstone, only the materials are of volcanic origin.

The materials produced by the volcano are, then—1. *Lavas;* 2. *Cinders;* 3. *Tufas;* 4. *Vapors* or *Gases*, which are mostly *vapor of water*, partly *sulphur gases*, and in some cases also *carbonic acid*, *muriatic acid*, and some other materials.

The *lavas* are of various kinds. They are more or less cellular; sometimes light cellular, like the *scoria* of a furnace; but more commonly heavy rocks with some scattered ragged cellules or cavities through the mass. A stream of lava in a crater, of this more solid kind, has often a few inches of *scoria* at top,—as a running stream of syrup may have its scum or froth. The most of the *scoria* has this scum-like origin. *Pumice* is a very light grayish *scoria*, full of long and slender parallel air-cells.

The lavas may be black or brownish, and greenish-black, in color, and very heavy (specific gravity above 2.9), as the *Dolerite* and *Basalt*, described on page 26; or they may be rather light (specific gravity under 2.7) and grayish in color, as *trachyte* and *phonolite*. *Phonolite* is a very compact feldspathic rock, giving a clinking sound under the hammer.

A volcanic mountain is made out of the ejected materials; either—(1) out of lavas alone; or (2) of cinders alone; or (3) of tufas alone; or (4) of alternations of two or more of these ingredients. As the centre of the mountain is the centre of the active fires, the ejections flow off or fall around it, and hence the form of a volcanic peak necessarily tends to become conical.

The average angle of slope of a *lava-cone* is from 3° to 10°; of a *tufa-cone*, 15° to 30°; of a *cinder-cone*, 30° to 45°; of mixed cones, intermediate inclinations according to their constitution.

B. Volcanic eruptions.

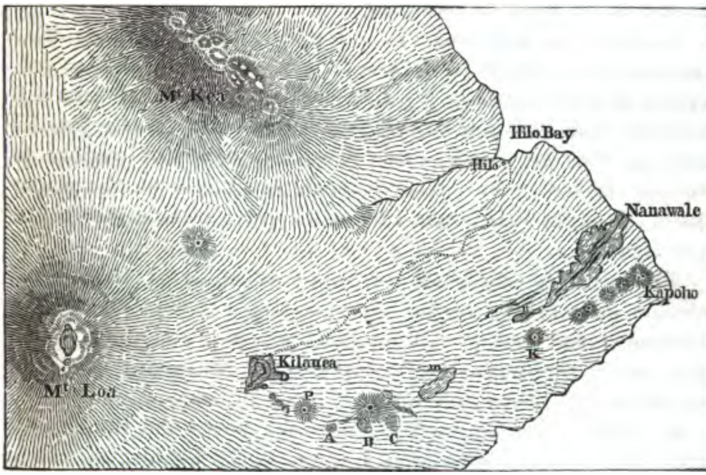
The process of eruption, though the same in general method in all volcanoes, varies much in its phenomena. The fundamental principles are well shown at the great craters of Hawaii, the southeasternmost of the Hawaian (or Sandwich) Islands.

1. **Hawaian Volcanoes.**—1. *General description.*—Hawaii is made up mainly of three volcanic mountains,—two, Mount Loa and Mount Kea, nearly 14,000 feet high; and one (the western), Mount Hualalai, about 10,000 feet. Mount Kea is alone in being extinct. The average slopes of the two highest are well shown in figs. 369, 370, on page 302, fig. 369 representing Mount Kea and 370 Mount Loa.

Mount Loa has a great crater at top, and another 4000 feet above the level of the sea (at *k*, fig. 370). The latter is the famous one called *Kilauea*, and also *Lua Pélé* or Pélé's pit, Pélé being, in the mythology of the Hawaians, the goddess of the volcano.

The accompanying map of the southeastern portion of

Fig. 371.



Map of part of Hawaii.

Hawaii shows the positions of Mount Loa and Mount Kea, and of the crater of Kilauea, besides other craters at the summit of Mount Loa, and on the sides at P, A, B, C, K, &c.

2. *Kilauea.*—The crater of Kilauea is literally a pit. It is three miles in greatest length, and nearly two in greatest breadth, and about seven and a half miles in circuit. It is large enough to contain Boston proper to South Bridge, three times over, or to accommodate 400 such structures as St. Peter's at Rome. The pit has nearly vertical sides of solid rock (made of lavas piled up in successive layers), and is 1000 feet in depth after its eruptions, and 600 when most filled with lavas (its present condition). The bottom is a

great area of solid lava; and it may be surveyed from the brink of the pit, even when in most violent action, as calmly and safely as if the landscape were one of houses and gardens. In some parts of it there are ordinarily one or more lakes or pools of liquid lava, and from these and other points vapors rise. The largest lake is sometimes 1000 feet or more in diameter.

3. *Action in Kilauea.*—The action is simply this. The lavas in the active pools are in a state of ebullition, jets rising and falling as in a pot of boiling water, with this difference, that the jets are 30 or 40 feet high. Such jets, in lava as well as water, arise from the effort of vapors to escape; in water the vapor is steam derived from the water itself; in lavas it is steam and other gases from materials in the lavas.

The lavas of the pools or lakes overflow at times and spread in streams across the great plain that forms the bottom of the crater. In times of great activity the pools and lakes are numerous, the ebullition incessant, and the overflowings follow one another in quick succession.

4. *Cause of eruption.*—By these overflows the pit slowly fills, and in the course of a few years the bottom is, consequently, 400 feet above its lowest level; so that the depth is thus reduced from 1000 to 600 feet. This addition of 400 feet increases 400 feet the height of the central column of liquid lava of the crater, and causes a corresponding increase of pressure against the sides of the mountain. The amount of this pressure is at least *two and a half times* as great as that which an equal column of water would produce. The mountain should be strong to bear it. The lavas at such times may be in a state of violent activity, and when so there is an addition to the pressure against the sides of the mountain, arising from the force of the imprisoned vapors.

The consequence of this increase of pressure, both from the lavas and the augmented vapors, may be, and has several times been, a breaking of the sides of the mountain. One or more fractures result, and out flows the lava through the openings. Thus simple are the eruptions of the Hawaian volcanoes.

In one such eruption the lavas first appeared at the surface a few miles below Kilauea (at P, fig. 371), and then again at other points more remote, A, B, C, m; and finally a stream began at *n*, a point 20 miles from the sea, which continued to the shores at Nanawale. Here, on encountering the waters, the great flood of lava was shivered into fragments, and the whole heavens were thick with an illuminated cloud of vapors and cinders, the light coming from the fiery stream below.

This eruption of Kilauea took place, it will be observed, *not over the sides of the crater*, but through breaks in the mountain's sides below; and the pressure of the column of lava within, along with the pressure of the escaping vapors, appear to have caused the break. In all known eruptions of Kilauea the process has been that described.

5. *Summit-crater of Mount Loa.*—Eruptions have also taken place within a few years from the summit-crater of the same mountain (Mount Loa), or at a point nearly 14,000 feet high above the sea; and in each case there has been, not an overflow from the crater, but an outflow through breaks in the sides of the mountain. In one case there was first a small issue of lavas near the summit, and then another of great magnitude about 10,000 feet above the sea-level. At this second outbreak the lava was thrown up in a fountain, or mass of jets, several hundred feet high; and thus it continued in action for several days. The forms of the fountain of liquid fire were compared by Rev. Mr. Coan to the clustered spires of some ancient Gothic cathedral.

6. *Cause of the jet or fountain of lava.*—The pressure producing this jet was that of the column of lava between the point of outbreak and the level of the lavas in the summit-

crater 3000 to 4000 feet above. The same pressure in connection with confined vapors must have caused the breaking of the mountain in which the eruption began. There have been no great earthquakes accompanying the Hawaiian eruptions, sometimes not even slight ones, the first announcement being merely "a light on the mountain." Moreover, when the summit-crater has been thus active, Kilauea, though 10,000 feet lower on the same mountain and even a larger pit-crater, has shown no agitation and no signs whatever of sympathy.

7. *Conclusions.*—These cases of eruption indicate—(1) that the lavas go on gradually increasing the pressure in the interior by their accumulation and rising to a higher level; and that finally, when the mountain can no longer resist it, it breaks and lets the heavy liquid out. They show (2) that while earthquakes may attend volcanic action, they are no necessary part of it. They show (3) that lavas may be so very liquid that no cinders are formed during a great eruption. For in the ebullition of the lava in the boiling lakes of Kilauea, the jets (made by the confined vapors) are thrown only to a height of 30 or 40 feet; and on falling back, the material is still hot and does not become cooled fragments; it either falls back into the pool or lake, or becomes plastered to its sides.

At some of the eruptions of Mount Loa the lava has continued down the mountain to a distance of 30 or 40 miles.

2. **Vesuvius.**—Vesuvius is an example of another type of volcano. The lavas are so dense or viscid that jets cannot rise freely over the surface: the vapors are kept confined until they form a bubble of great dimensions; and when such a bubble, or a collection of them, bursts, the fragments are sometimes thrown thousands of feet in height. The crater, at a time of eruption, is a scene of violent activity, and cannot be approached. Destructive earthquakes often attend the eruptions.

The lavas at Vesuvius may flow directly from the top of the crater; but they generally escape partly, if not entirely, through fissures in the sides of the mountain.

3. **Comparison of Mount Loa and Vesuvius as to causes of eruption and nature of the mountains.**—Of the two causes of eruption—hydrostatic pressure and elastic force of confined vapors—the latter may be the most effective at Vesuvius, while the former is so at Hawaii. Mount Loa on Hawaii is an example of the great free-flowing volcanoes of the world, and the mountain is almost wholly a lava-cone. Vesuvius is an example of a smaller vent with less liquid lavas; and the cone is made up of both solid lavas and cinders.

4. **Lateral cones of volcanoes.**—In eruptions through fissures the lavas may continue issuing for some days or weeks through the more open or widest part of the fissure, and consequently form at this point a cone of cinders or lavas. Thus have originated innumerable cones on the slopes of Etna and other volcanic mountains.

5. **Submarine eruptions.**—The eruptions may sometimes take place from the submarine slopes of the mountain when it is situated near the sea, as has happened with Etna and Mount Loa; and in such cases cones of fragmental lavas or solid layers may form under water about the opened vent. Fishes and other marine animals are usually destroyed in great numbers by such *submarine* eruptions.

6. **Subsidences of volcanic regions—Overwhelming of cities.**—Among the attendant effects of volcanoes are the sinking of regions in their vicinity that have been undermined by the outflow of the lavas, and the tumbling in of the summit of a mountain. Another is the burial, not only of fields and forests, but even of cities and their inhabitants, by the outflowing streams, or the falling cinders and accumulating tufas. Pompeii and Herculaneum are two of the cities that have been buried by Vesuvius; and every few years we

hear of some new devastations made on habitations or farms by this uneasy volcano.

C. Subordinate volcanic phenomena.

1. **Solfataras.**—In the vicinity of volcanoes, and sometimes in regions in which no volcanoes exist, there are areas where steam, sulphur vapors, and perhaps carbonic acid and other gases, are constantly escaping. Such areas are called *solfataras*. The sulphur gases deposit sulphur in crystals or incrustations about the *fumaroles* (as the steam-holes are called); and alum and gypsum often form from the action of sulphuric acid (another result from the sulphur gases) on the rocks.

Fountains or springs of hot waters are common in such places, and are often so abundant as to be used for baths.

2. **Geysers.**—In Iceland at the *Geysers* the heated waters are thrown out in intermittent jets in some cases to a height of 200 feet. Subterranean streams arising in the mountains are supposed to pass over heated rocks, and then to be forced upward by the vapors produced by the heat. Such heated waters act on the rocks, decomposing them, and thereby become slightly alkaline and also *siliceous* solutions. The silica thus taken into solution is deposited again around the Geysers in many beautiful forms, besides making the bowl of the cavity or basin from which the waters are thrown out, and forming numerous petrifactions.

When the basin of a boiling pool consists of earth or mud, *mud-cones* are formed, as in California.

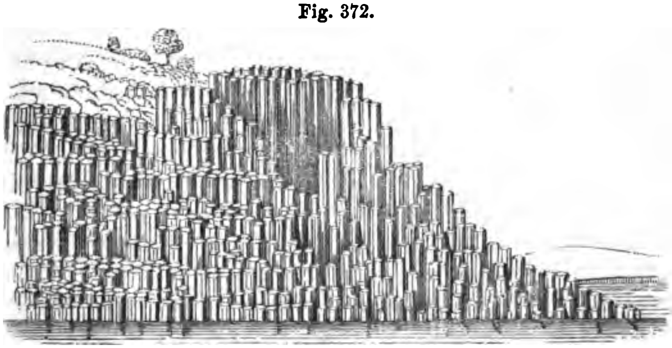
2. IGNEOUS ERUPTIONS NOT VOLCANIC.

It has been stated that eruptions of volcanoes generally take place through fissures. Fissures have often been made in the earth's crust and filled with liquid rock, also, in regions remote from volcanoes. Such fractures of the crust of the earth must have descended to some seat of fires, if not through to the earth's liquid interior. Whatever cause was sufficient to break through the crust would have sufficed to press out the liquid rock beneath. The narrow mass of igneous rock which fills such fissures is called a *dike* (p. 30). The igneous rock is generally without cellules or air-cavities; or, if present, they are neatly formed, and not ragged like those of lavas. Such rocks having the cavities filled with minerals (as quartz, zeolites, etc.) are called *Amygdaloids.*

The most common rocks of such dikes are *dolerite* and *basalt* (p. 26), and next to these, *diorite* and *porphyry.* The *dolerite*, *basalt*, and *diorite* are often called *trap.*

Dikes of rocks of this kind are mentioned and described on p. 165 as occurring in various parts of the Eastern border region of North America,—constituting the Palisades on the Hudson; Bergen Hill and other heights in New Jersey; many bold bluffs in Connecticut between New Haven and its northern boundary; Mount Tom and Mount Holyoke and other elevations in central Massachusetts, and ridges in Nova Scotia near the Bay of Fundy. The rocks of the Salisbury Craigs near Edinburgh, and of the Giants' Cause-

Fig. 372.



Basaltic columns, coast of Illawana, New South Wales.

way and Fingal's Cave, are other examples. They are common on all the continents, especially in the regions between the summits of the border mountains and the ocean, which are usually between 300 and 700 miles in breadth; as, for example, between the Appalachians and the Atlantic, and between the Rocky Mountains and the Pacific.

These basaltic and doleritic rocks are often columnar in their forms, as illustrated in the preceding sketch of a scene in New South Wales. The Giants' Causeway is remarkable for the regularity of its columns. Similar scenes of great beauty occur on Lake Superior, and some of less perfection in the Connecticut River valley and the Palisades on the Hudson. These columns were formed when the rock cooled, and are due partly to contraction and partly to a concretionary structure produced in the process of cooling. The size of the concretions in such a case determines the diameter of the columns, and depends on the amount of material and the rate of cooling, the size being larger the slower the rate.

3. METAMORPHISM.

1. *Nature of metamorphism.*—The term *metamorphism* signifies *change* or *alteration;* and in Geology, a *change* in the earth's rocks or strata, under the influence of heat below fusion, resulting in crystallization, or, at least, firm solidification: as when *argillaceous shale* is altered to *roofing-slate* or *mica schist; argillaceous sandstone*, to *gneiss* or *granite;* common *compact limestone*, to *granular limestone* or *statuary marble;* a common *siliceous sandstone*, to a hard *grit* or to *quartzite.* The more common kinds of rocks resulting through metamorphism are described on pages 23, 24.

2. *Effects.*—The effects of metamorphism include not only —(1) solidification and (2) crystallization, but also—

(3.) A change of color; as the gray-and-black of common limestone to the white color or the clouded shadings of marble; and the brown and yellowish-brown of some sandstones colored by iron, to red, making red sandstone and jasper-rock.

(4.) In most cases, a partial or complete expulsion of water, but not in all; for serpentine, a metamorphic rock, is one-eighth (or 13 per cent.) water.

(5.) A partial or complete loss of bitumen, if this ingredient be present; as when *bituminous coal* is changed to *anthracite* or *graphite* (pp. 76, 160).

(6.) An obliteration of all fossils; or of nearly all if the metamorphism is partial.

(7.) In many cases, a change of constitution; for the ingredients subjected to the metamorphic process often enter into new combinations: as when a limestone, with its impurities of clay, sand, phosphates, and fluorids, gives rise under the action of heat not merely to white granular limestone, but to various crystalline minerals disseminated through it, such as *mica*, *feldspar*, *scapolite*, *pyroxene*, etc.; or when an argillaceous sandstone becomes a gneiss or schist full of *garnets*, *tourmaline*, *hornblende*, etc.

Thus *metamorphism* often fills a rock with crystals of various minerals. Even the gems are among its results; for *topaz*, *sapphire*, *emerald*, and *diamond* have been produced through metamorphic action. What is of more value, this process makes out of rude shales and sandstones hard and beautiful crystalline rocks, as granite and marble, for architectural and other purposes. Man's imitations of nature in this line are seen in his little *red bricks*.

3. *Process.*—*Water* and *heat* are two agencies essential in metamorphism.

Metamorphism has taken place generally when the rocks were undergoing great disturbances or uplifts, foldings and faultings, and, therefore, when the conditions were favorable for the escape of portions of the earth's internal heat. This heat has penetrated the wet rocks. The water or moisture within the rocks has rendered them good conductors of heat, and has aided directly in conveying the heat. Moreover, where the heat was above 212° F., or the boiling point of water,—as it probably has been in most cases of metamorphic change,—all of it has passed to what is called a *superheated* state; and in this state it has great power in dissolving and decomposing minerals and promoting new combinations and crystallizations. Under such circumstances, the moisture becomes itself a solution by taking up mineral substances from the rock in which it is at the time; and these added materials are the source of a large part of its power in making changes; for if it thus becomes an alkaline siliceous solution, like the waters of the Geysers (see p. 310), it may not only deposit quartz in all seams or cavities, if the temperature favors this, but it may, under other favorable circumstances, help in making *feldspars*, *micas*, and many other alkaline siliceous minerals; or if the alkalies are mostly absent and iron is present, the siliceous waters may promote the crystallization of *staurotide* and *hornblende*.

The change of a siliceous sandstone to a grit or quartzite requires nothing but these conditions; for the moisture in such a rock would become, when subjected to slow heating, siliceous, from the material of the sandstone, and the silica taken up would be deposited again as the rock cooled, and so cement and solidify the whole into a true quartzite. Such quartzites often contain some feldspar, a mineral that would also be formed if a little alkali and alumina were present.

These are examples of the various ways in which heated and superheated waters may promote metamorphic changes. Direct experiments have shown that these kinds of crystallizations do result from the action of heat.

Pressure is requisite for most metamorphic changes. Limestone heated without pressure loses its carbonic acid and becomes *quick-lime*, as in a lime-kiln; but if under pressure, the carbonic acid is not driven off. The possibility of the crystallization of limestone by heat, under pressure, has been proved by direct experiment. The necessary pressure may be that of an ocean above; or it may be only that of the superincumbent rocks, a few hundred feet of which would be quite sufficient.

The *similarity* of argillaceous sandstones to gneiss or granite is often much greater than appears to the eye. They have been made by the wear of just such rocks as gneiss and granite; and the sand of the former is the quartz of the latter, the clay of the former frequently only the pulverized feldspar of the latter, and mica may be in grains in the former as it is in the latter: so that the change would in such a case be mainly a change in the state of crystallization. By heating a bar of steel to a temperature far short of fusion, and cooling it again, it may be made coarse or fine steel, the process changing the grains by causing many small grains to combine to make the large ones in the coarser kind and the reverse for the finer kind. There is something analogous in the change of an argillaceous sandstone to a gneiss or granite above described.

If the sandstone or shale contains little or no alkali, its metamorphism cannot produce a gneiss or mica slate, since feldspar, one of the constituents of these rocks, contains an alkali as an essential ingredient. The result will necessarily vary with the constituents of the original rock, and the heat and other conditions attending the metamorphism.

Often, however, the material derived from the wear of gneiss and granite and other rocks is not only pulverized, but also more or less decomposed:—the feldspar, for example, undergoes a change in its alkalies, or loses them altogether, they being carried off by waters, or the mica may lose its oxyd of iron and alkalies; or waters may bring in oxyd of iron or other ingredients; and so on: and in such a case the process of metamorphism could not, of course, restore the original rock. The new rock made would contain no feldspar if the alkalies had been removed; but it might be an argillite, or, if much oxyd of iron were present, a hornblende rock, or some other kind, according to the nature of the material subjected to the change, and the amount or continuance of the heat.

Examples of the metamorphism of extensive regions of the earth have already been mentioned on pages 75, 156, and these pages should here be perused anew. In the case of the Azoic formation, the rocks of a large part of the earth's surface may have been in process of crystallization at one time; and in that of the Appalachian chain changes of this kind took place not only over the region from Labrador to Alabama, but simultaneously in Europe and probably on the other continents.

4. FORMATION OF VEINS.

1. *Nature and origin of spaces occupied by veins.*—Veins occupy (1) the cracks and fissures made in rocks and (2) openings between their layers, especially those of schistose or slaty kinds. They are produced in great numbers when a region of rocks is undergoing uplift, or when a folding of the strata is in progress. The fractures may descend through the crust, or to regions of melted rock, as in the case of the formation of dikes (p. 310); they may descend to depths of intense heat without reaching liquid rock below; they may intersect either several strata lying together, or only one of a series, for some rocks will become fractured by the same circumstances that will leave others unbroken.

2. *Filling of veins.*—Whatever the cause of the fractures, the causes that produce so great metamorphic changes would fill the fissures and openings (when not so deep as to reach to regions of liquid rock) with minerals from the rock either side of the fissure. The heated waters, or moisture, of the rocks would slowly fill all cavities. A movement in the moisture toward any empty space would take place; and the moisture of the rock around, on reaching the space

or fissure, would lose its mineral material by its crystallization against the walls; the place of that which was thus lost would be resupplied at once by other portions, with the same result; and thus a constant current would be kept up as long as the supply held out, or until the cavity or fissure were filled. In the filling of veins, the material comes mostly from the rock adjoining some part of the fissure.

However minute the quantity of any material in the adjoining rock, even if it be wholly undistinguishable by any chemical investigation, the penetrating heated and mineralized moisture would find it, and, taking it into solution, convey it to the forming vein. Gold, and the material of emeralds and other metals and gems, have thus been gathered into veins.

The kind of crystallizations in the fissure would depend largely on the heat present and the nature of the rock adjoining; and the heat would depend on the depth of the fissure. If the vein reached down to depths of intense heat, where cooling would be exceedingly slow, the materials would be more coarsely crystallized than if only to shallow depths.

Metallic ores may often rise in the fissures, in vapors or solutions, from depths far below those at which they are deposited.

Some strata, owing to their nature, might afford almost nothing for the fissure, and the filling of this part would then come from the portions above or below.

3. *Simple and banded veins.*—Veins filled by this lateral inflow of material would sometimes be *uniform* in texture throughout, as in many quartz veins or seams; or they might be *banded*, like most metallic veins (p. 30). In the formation of the latter, the infiltrating process might bring in for a while one kind of mineral, as *feldspar*, and deposit it over the walls of the fissure; then, through a modification of the temperature, or some other change, *quartz;* then, an

ore of lead, or one *of zinc*, or one *of copper;* then *quartz* again, or calcite; and so on until the vein was filled.

In these ways argillaceous and talcose schists have been filled with quartz veins or seams, the repositories of gold and of various ores. (These auriferous quartz veins in schists are often only the filling of cavities opened *between the layers*, and which are due to the contortions the schists underwent during the uplifting, folding, and metamorphic process.) By similar methods granitic and various metallic veins have been formed in rocks of other kinds.

Thus the earth's metals have been gathered from rocks, in which they were disseminated in such infinitesimal quantities as to be of no service to art, into generous veins, and so placed within reach of the miner.

V. MOVEMENTS IN THE EARTH'S CRUST, AND THEIR CONSEQUENCES.

The subjects here included are the following:—

1. Origin of changes of position and level in the earth's crust or rocks.
2. Origin of cleavage and jointed structure in rocks.
3. Earthquakes.
4. Origin of the earth's general features, and of the successive phases in its history.

1. CHANGES IN POSITION AND LEVEL.

Change of level may proceed from undermining, either by subterranean waters (p. 281), or by volcanic ejections (p. 309). But the results of these causes are comparatively local.

The causes of more comprehensive character, usually appealed to in order to explain the origin of the earth's mountains and its oscillations of level, are the following:—

1. *Vapors suddenly evolved beneath some portion of the earth's crust.*—This cause has been commonly regarded as of the

highest importance, especially with reference to the elevation of mountains. There are two difficulties with regard to it. (1.) No open cavities of sufficient extent for the purpose can be proved to exist beneath mountains where such vapors could spread and act. (2.) If the explosion were to take place,—as, for example, beneath the Andes,—the mountains would not stay up on a mere bed of condensible vapors; they are *very heavy*, and require solid support.

2. *Weight of the accumulations of sedimentary formations in progress over any region, as the Appalachian.*—This cause might possibly produce subsidence in a region like the Appalachians, and some uplifts either side as a secondary effect from the lateral pushing which such a subsidence might occasion. But, although the subsidence in the Appalachian region greatly exceeded the elevations (p. 155) there were some elevations alternating with the subsidences in the course of the Paleozoic ages; and, later, in the progress of the formation of the mountains, a series of flexures on a great scale, over the whole breadth of the region, was produced in addition to elevations (p. 156); and such effects cannot proceed from mere weight or gravitation.

3. *Expansion and contraction from change of temperature.*—If a portion of the crust, or of its rocks, becomes heated from the action of heat below, elevation will result, because an increase of heat causes expansion; and expansion must show itself in a rising of the surface. Conversely, if a heated region cools, there will be contraction; and this contraction may cause two effects: (1) a sinking in the surface; (2) a fracturing of the rocks, or shrinkage-cracks. If there are no fractures produced, the whole result will appear in the sinking.

This cause of change of level acts with extreme slowness.

The subsidence and elevation of the region of the Temple of Serapis, on the coast of Italy just north of Naples, have been attributed to this cause.

4. *Tension in the earth's crust resulting from the contraction of the globe.*—In the remarks on the Appalachian revolution (p. 160), it was shown that the effects proved beyond question—(1) the action of *lateral* pressure; (2) that this lateral pressure was exerted in the earth's crust, and in a direction from the Atlantic Ocean, or at right angles to the course of the mountains; (3) that it was exceedingly slow or gradual in action. This slow-acting pressure, as in the third cause above explained, is a power residing, through some cause, in the crust itself of the earth.

The facts observed in the Appalachians are common facts all over the globe wherever there are uplifted rocks or mountains. Nearly all tilted rocks are actually folded rocks. The flexures vary in extent from the slightest arching of the strata to bold and lofty close-pressed folds, as illustrated on pages 41, 42. This flexed condition could have been produced only by lateral action or pressure, as a result of the cause alluded to. This cause has, therefore, produced universal effects over the globe.

The facts in Geology leave little room for doubt that the earth was once in fusion, and has been through all time a *cooling* globe. If it has been a cooling globe, it has been undergoing contraction, or a gradual diminution of size, just as a globe of glass or lead will become smaller on slow cooling. Now, in the case of a cooling sphere, if an exterior hard crust be early formed, the contraction afterwards going on within will bring a great strain on this crust, because it is unyielding and cannot accommodate itself to the contraction in progress; and this strain, if the crust be not thick enough to stand firm, will result either in breaking the crust and pulling inward some portions and so pressing other parts out, or in making the crust to rise into folds. In a drying, and therefore contracting, apple, the skin becomes folded, because flexible. In a drop of glass (called a Prince Rupert's drop) which has been formed by rapid cooling (the outside thereby being first cooled), the whole is under powerful tension or strain. The exterior is so hard, of so uniform texture, and of so even surface, that it cannot become folded, and yet it remains unbroken; but if the faintest scratch of a file be made, so as to disturb the equilibrium in the mass, the whole goes to fragments, even with explosion. The scratch of the file takes out particles from the surface, and acts like the taking out of a line of stones from a heavily weighted arch; the destruction is in principle the same as in the case of the arch.

In a cooling sphere like the earth there must have always been a tension or strain in the crust from this cause; and, as the earth is not a glass globe of even texture and surface, the cause should have produced fractures and flexures, bulgings and sinkings, over its various parts, and at various times in the course of the earth's history; while gentle oscillations of level in the crust must have been in constant progress.

5. *Sufficiency of the last-mentioned cause.*—This cause is a sufficient cause for all flexures of strata, because it is indefinite in power and very slow in its action. A sudden force would throw strata into a chaos. But experiment has proved that by an exceedingly gradual movement any bed of rock, however inflexible, especially if moistened and heated, and even cold ice, may be made to rise into an arch, and then into a series of arches or folds, by a slowly acting lateral pressure.

This cause is one that affords a firm support for the lifted continent or mountain-chain as it rises; for in its action one portion of the earth's crust is *pushed* up by another, and the former, therefore, rests on the mass by means of which it was raised. It remains where it is placed by the irresistible pressing force.

This cause is sufficient to have made the mountains of the globe. Mountains are relatively very small elevations on the earth's surface. Etna, although 10,000 feet high, would stand up but *one-tenth* of an inch on a globe 110 feet in circumference, or 35 feet in diameter,—as large as many a capacious house; and *one-hundredth* of an inch would correspond on such a globe to 1000 feet, which is the mean height of all the continents. The wrinkles on an orange are proportionally larger than those of the earth or her mountains: the earth has relatively the smoother surface.

It is obvious, therefore, that the height or extent of mountain-elevations is no difficulty before such a force as that contemplated. Chains as lofty as the Himalayas, valleys as deep as the profoundest oceanic basin, flexures as numerous and close as those of the Appalachians, Juras, and other chains, and fractures and faults thousands of feet in depth, may all proceed from this one universal and ever-acting cause. The changes of level now in progress in Sweden, Greenland, and some other northern regions, may be due to its present power.

6. *Change of water-level may be caused by change of level in the bottom of the oceanic basins.*—Changes of level are ordinarily measured by reference to the water-level,—that is, the level of the ocean. Thus, if a region is 100 feet above the ocean in one period and 200 in a following, the first inference is that the land has been elevated 100 feet. It is plain, however, that this inference is correct only in case the bottom of the ocean has remained unchanged in level. The oceanic area is three times as large as that of the continents; and, consequently, if the earth's crust beneath the oceans were throughout to sink *one-third of* 200 *feet*, the water-level would sink away from the land to a level 200 feet below the present level. There is no reason why the oceanic part of the crust should not have been as liable to change of level by subsidence as that of the land by elevation; in fact, there is strong evidence for believing, as mentioned

beyond, that the oceanic basin has always been the more sinking portion of the crust, or that most subject to subsidence. It is, therefore, essential for accurate conclusions, in cases of *apparent* elevation, that the possibility of changes over the oceans should be considered. It is probable that the present *average* height of the continental lands above the ocean, or 1000 feet, is wholly owing to the sinking of the ocean's bed which was in progress through the successive geological ages.

2. SLATY CLEAVAGE AND JOINTS.

1. *Slaty cleavage.*—On page 36 it has been stated that the lamination, or slaty cleavage, of the great beds of roofing-slate does not, as in shales, conform in direction to the original layers or beds, but, on the contrary, is oblique to the bedding and sometimes nearly at right angles to it. As slates were originally shales, some change has come over them in the process of metamorphism, which has almost or quite obliterated the original lamination and produced another in a new and transverse direction.

The shales during a metamorphic process are not only hardened and rendered, it may be, semi-crystalline, but they are also uplifted or folded. This uplifting and folding is a result of long-continued lateral pressure, as explained on the preceding pages. The slaty cleavage *results directly from the lateral pressure* attending the uplifting and flexing, and is *at right angles to the direction of the pressure.* Tyndall has found that even beeswax may be rendered lamellar in structure by pressure alone; and if this is possible with a substance of so uniform texture as beeswax, there is no question about it with regard to clayey rocks. The pressure tends to force all lamellar particles, as scales of mica, or flattened grains of sand, into parallel planes having the direction just stated, and also to flatten out all air-spaces in the same direction; and in these ways the pressure is enabled to produce the slaty structure. The same structure actually exists in the ice of many glaciers, and from essentially the same cause.

2. *Joints.*—Joints in rocks are described on page 35 as planes of fracture descending to great depths, and as being systematically parallel in the same region, and also in great numbers. This parallelism is similar to the parallelism in the slaty structure, and both have the same origin,—the lateral pressure attending movements in the earth's crust. Joints occur in rocks of any kind, even coarse conglomerates and granites as well as sandstones, limestones, slates, and shales, and also in rocks that are not inclined or but little so. While the slaty structure is an effect of successive movements in the action of pressure, the joints may proceed both from such movements and from a simple yielding to a progressing tension or strain. This force, acting from a common direction through a long period, produces in the end a series of deep fractures, parallel in course and therefore one in system. Other joints at right angles to this system may result simultaneously, making a transverse system. Or the action of the same force in a later period or age, from a *different direction*, may cause a system of joints oblique to the first. Thus, two or more systems of joints may be produced in the rocks of the same region.

Joints and slaty cleavage are, therefore, effects of the great and universal power which has caused the oscillations, uplifts, and flexures in the earth's crust.

3. EARTHQUAKES.

1. *Nature of earthquake-vibrations.*—Earthquakes are vibrations in the material of the earth's crust. A shock or concussion produced by a fracture or movement at any point causes vibrations in the rocks, and these vibrations travel outward from this point until they finally die out.

The vibrations in ice made by skaters may be heard for miles if the ear be placed close to the ice, because these vibrations travel far in a layer of such material. So it is, also, in the earth's rocks, although they are of less even texture and surface.

The vibrations are of different kinds:—(1) a simple shaking, without any actual displacement in the rocks; (2) a more powerful vibration, where there are both a shaking and a displacement, as when a shove, fault, or uplift suddenly takes place; (3) very rapid vibrations, causing the sensation of sound.

2. *Effects of earthquakes over the land.*—Earthquakes are well known to result often in the destruction of buildings, or even cities; in the opening of profound cracks in the ground, in which great numbers of people are sometimes engulfed; in the displacement of rocks and trees, and starting of avalanches of gravel and stones down precipices.

3. *Earthquake oceanic waves.*—An earthquake-vibration, when communicated to the ocean, causes great and powerful waves, which sometimes travel for thousands of miles. The earthquake at Valdivia on the coast of Chili, in 1837, produced a series of waves which deluged the eastern shores of Hawaii, 6000 miles distant; and an earthquake in 1854, at Simoda in Japan, sent waves across the Pacific to Oregon and California, which were detected there by the self-registering tide-gauges of the Coast Survey.

Oceanic earthquake-waves, in 1746, swept up the coast of Peru, and carried a frigate from the harbor of Callao several miles over the land, besides sinking 23 vessels; and during an earthquake on the coast of Spain, in 1755, the sea rushed up the land in a wave 40 feet high in the Tagus and 60 feet at Cadiz; and the same wave was 8 to 10 feet high on the coast of Cornwall, England.

These earthquake-waves have been an agency of great power and of very important results in the course of the earth's ancient history, deluging the land, destroying life, both of the sea and land, and sweeping away beaches and stratified deposits.

4. *Causes of Earthquakes.*—Whatever causes are capable of producing changes of level or position in the earth's crust may be causes of earthquakes. Thus, the undermining of strata, the evolution of vapors about volcanoes, tidal or other movements in the earth's liquid interior, tension from change of temperature, as in local cases, or in the earth's slow cooling, must have each produced their earthquakes. The last cause must have been the most common and comprehensive, if it is the cause of the larger part of the oscillations and uplifts over the earth. It may be the cause of the more powerful and extensive earthquakes of the present day, since tension within from the progress of cooling cannot yet have ceased. The cracking sounds in a stove-pipe as a furnace is rapidly heating or cooling are a result of that tension from expansion or contraction which accompanies change of temperature; for there is a strain produced, and then a yielding with loud sound. They exemplify, on a small scale, the lighter kind of earthquakes resulting from the earth's secular refrigeration.

According to Prof. Perrey of Dijon, there is some correspondence between the occurrence of earthquakes and the times of the ocean's tidal movements, and he infers, consequently, that there are tides in the earth's interior liquid corresponding to those of the ocean, making themselves manifest in earthquake-vibrations. Further investigation appears to be required to establish this as an actual cause of earthquakes at the present time.

4. ORIGIN OF THE EARTH'S GENERAL FEATURES, AND OF THE SUCCESSIVE PHASES IN ITS HISTORY.

1. *General laws as to the Earth's features.*

The first two of the following laws have been stated and explained on pages 8 to 11. The others are illustrated in the course of the volume. It should be understood that the *border region* of a continent includes the ridges of the border mountains and the country which lies between them and the adjoining seacoast. Thus, the western border region of North America is that lying between the summits of the Rocky Mountains and the Pacific coast, an area 300 to 800 miles wide; and the eastern is that extending from the western ridges of the Appalachians to the Atlantic, an area 200 to 300 miles in width.

(1.) The continents have in general high borders and a low interior, and are, therefore, *basin-shaped.*

(2.) The *highest* border faces the *largest* ocean.

(3.) The effects of heat after Azoic time are more marked along the *border regions* of the continents than over their interior. It is sufficient, in illustration of this law, to refer to the fact that nearly all the metamorphism of North American rocks, after that of Azoic time, took place either in the Atlantic or the Pacific border regions; and that the volcanoes of this and the other continents, with a rare exception, are confined, and have always been confined, to the *border regions* of those continents, and are absent from the interior regions. One exception exists in central Asia, in the Thian-Chan Mountains. The volcanoes of Europe and western Asia pertain to the region bordering on the Mediterranean and Red Sea.

(4.) The effects of heat are *most marked* on the border region adjoining the *largest* ocean. This law is also exemplified on all the continents. The great ocean—the Pacific—has a girt of volcanoes, as stated on page 300; the small Atlantic, almost none. In North America a large number of volcanoes, from 10,000 to 18,000 feet in height, exist in the western border region, but not one east of the summit of the Rocky Mountains; metamorphic rocks, and those igneous rocks that have been ejected through fissures, are almost the sole effects of igneous action found in the Atlantic border region.

In South America there are similar facts: the volcanoes of the *Pacific* border region are very numerous, and vary from 25,000 feet in height to 10,000 and under. On the *Atlantic* side there are none. In Africa there is a small volcanic region on the coast adjoining the Gulf of Guinea, in the Cameroons Mountains; but a number of large volcanoes exist in eastern Africa through Abyssinia and the Red Sea.

In the great Orient there are hundreds of volcanoes on the Pacific side, in the outer range of heights constituting the islands off the coast, as the Philippines, Japan, the Kuriles, etc., and in Kamtchatka; but none on the coast of Norway, and only a few small regions in Europe, and these, as has been said, are connected with the Mediterranean region.

(5.) *The transverse mediterranean seas of the world abound in volcanoes.*—The East Indies between Australia and Asia, the Red and Mediterranean seas between Africa and Europe, the West Indies, as well as Central America, between North and South America, are notedly volcanic areas. The volcanoes of the Mediterranean region occur in Spain, France, Germany, Italy, Greece, Syria, and Armenia.

2. *Origin of the Earth's Features, and Phases of Progress.*

1. *The cause universal in action.*—The conformity of the continents in their reliefs to one model (p. 9) proves some common method of formation; and, as the continents occupy *one-third* of the earth's surface, this method of formation must have been dependent on some world-wide cause.

Since, moreover, the forms of the continents have a direct relation to the extent of the ocean (a relation so close that there is almost an exact proportion between the elevation of the border region of the continents and the capacity of the adjoining ocean), both must have resulted from the same universal method of development.

2. *Continents and oceans outlined in the beginning.*—The making of the continents according to a model implies a regular or systematic course of progress throughout the earth's history. If the ocean and continents had at times changed places (if Asia, for example, had ever been the area of the deep ocean, and the bed of the Pacific the dry land of a continent, and thus oceans and continents had alternated with one another), the comprehensive relation between the extent of the oceans and the heights of the continental borders would have been impossible. Direct observation has proved, moreover, that the continent of North America was in actual existence, and of nearly or quite its present extent, by the close of the Azoic age, if not before (p. 84); that, although mostly submerged, it lay in the Primordial period near the surface, part constituting the Azoic dry land, part rising as sand-banks, beaches, and dunes above the tides, a large part in shallow waters within reach of the waves, while other portions were at somewhat greater depths.

The above proposition is proved also by the whole course of geological progress, the great fact in which is that the elevating and oscillating forces which were in action in Azoic times continued to be, for the most part, the same *in direction* through all subsequent time to the close of the Tertiary. (See pages 77, 146, 245).

The law of form, the law of progress, and the law of relation to the oceans, each and all afford decisive proof, therefore, that the continents were fixed in their positions *in the beginning*, and determined at the same time, also, in their main outline; and, if the outlines of the continents were fixed, those of the oceans were so also, since they are one and the same.

3. *Oneness of the cause.*—One cause acting continuously

from the beginning of the earth's crust to the end of geological history has, therefore, originated by concurrent movements the oceanic basin and the continental plateaus. This cause has not merely raised the continental areas and sunk the oceanic. It has made their mountains and their plains. It has evolved, not isolated or scattered heights, but heights in ranges and chains, and placed them with so much system over the surface that a continent has as truly its type of form as an animal. In each case there is the same evidence of a system of evolution or development, starting from a condition of memberless simplicity, and ending in a complex structure in which every part has harmonious reference to a specific purpose.

4. *Nature and mode of action of the cause.*—In explaining the origin of mountains, the complete efficiency and universality of one great cause was pointed out. This cause—contraction from cooling—appears to have all the requirements, as far as they can reside in any physical cause, that are necessary for the grander result here in view,—the development of the earth's physical features. It has acted uninterruptedly through all time. It must have acted with simultaneous and accordant results throughout the whole crust, oceanic and continental. But, while everywhere in simultaneous and systematic movement, there have been produced a diversity of effects, and a diversity under system.

In a cooling globe, the part which earliest became cold and rigid would not afterwards yield, under the influence of the progressing contraction, as readily as the rest, and would therefore remain comparatively firm while the other part was gradually subsiding. There might hence be from the first a *firmer* or more stable portion, and a *sinking* or *depressed* portion; and thus would begin the continental and the oceanic areas. The waters of such a globe would be deepest in the depressed portion, if not wholly contained within it.

If, then, the oceanic portions of the crust were the great contracting areas, and the continental plateaus the parts comparatively stable, or those contracting least, the sinking of the crust of the former would bring the greatest strain against the *borders* of the rigid portion, that is, the *borders of the continental plateaus.* Here, therefore, the lateral pressure or pushing action would show its greatest effects: (1) in upliftings of the crust; (2) in foldings and fractures; (3) in metamorphism through escaping internal heat; (4) in igneous ejections through fissures and volcanic vents. The continents subjected to such a force would have their border regions elevated thereby, and would thus receive that basin-like shape which characterizes them. Moreover, as the deepest and largest oceanic basin is a result of the greatest amount of contraction over the largest area, the mountains on the border of the *largest* ocean would be highest, the fractures deepest, and the volcanoes, since they are opened over deep fractures, most numerous, as have been shown to be true (pp. (10, 300).

The cause considered may also produce mountains over the interior of a continent, as it does minor uplifts, and especially so if the continent be of great breadth. For contraction must have been ever in progress beneath the continental plateaus, as well as the oceanic basin. It is hence natural that the great Orient, 6000 miles in width from Britain to Japan, should have its Urals as a nearly north and south chain between Europe and Asia.

The facts and the theory seem thus to be in unison. There can be no doubt that plications, fractures, and mountain-lifting have resulted through tension or lateral pressure in the crust from some cause. No cause of such tension has been pointed out but that of gradual contraction through the cooling of the earth. The cause would give systematic results; it would produce general uniformity of action and progress through successive ages; and it would lead to that family likeness which subsists between the continents, while admitting also of those diversities which distinguish them.

5. *Catastrophes and revolutions, or abrupt transitions in history.*—A cause producing the oscillations of the earth's crust and the elevation of mountains would also occasion catastrophes to the life of the globe, and abrupt transitions in the series of strata.

If the raising of a continent from the ocean, or of a large portion of it, were to take place under the action of such a cause, an extinction of marine life would be a necessary consequence; or, if a sinking of a continent beneath the waves should occur, an extinction of terrestrial life would result. Changing simply the depth of the water might also cause extinctions, since the oceanic species living between high and low tide level (or in the *littoral* zone, as it is called) are mostly different from those below; and those living between low-water and 90 feet (or in the *Laminarian* zone) are almost all different from those of greater depths.

These oscillations might cause the extinction of life, also, by *changing the climate* of the globe, as explained on page 256.

Moreover, all changes of level, causing submergence or emergence of the land, or even varying the depth of water, would change more or less the courses of currents in the seas and the region of wave-action, and would consequently change the *kinds of rocks* in progress, as from sand-beds to shales, or to conglomerate, and the reverse. Again, an extermination of the animal life (corals, crinoids, &c.) of a continental sea by any oscillation or other cause would stop the formation of limestones; and the extermination (as by submergence) of the plants of the land would cut short the coal-plant accumulation, to be resumed again only when the land should be anew in a condition to grow the terrestrial vegetation of marshes.

Under such a cause, there would be, at long intervals, epochs of *grander catastrophes*, resulting in metamorphism, in great fractures and foldings, and in the raising of mountains. The tension arising from contraction in such a crust would go on accumulating for long periods before it would be sufficient to overcome the resistance and cause great disturbances; and when a yielding finally took place, then the grander series of catastrophes would happen. There was one grand epoch of general metamorphism and folding at or near the close of the Azoic. Through the Paleozoic there were various oscillations of level, and, at a few times, disturbances and uplifts, with probably some metamorphism (as in the Green Mountains after the Lower Silurian); but no general epoch of change occurred in eastern North America or over the world until the close of the Paleozoic, when the Appalachian revolution took place.

After this epoch of the Appalachian revolution, there were, through Mesozoic time, changes of level or uplifts of limited extent; but not until the Cretaceous period was drawing to its close did another grand epoch begin,—the one in which the life of the Cretaceous world ended, and the great mountains of the continents were mostly made (p. 202).

3. *Illustrations from North America.*

1. *Simplicity of action in North America.*—The continent of North America stands isolated from all others, having an ocean on the east, an ocean on the west, the small Arctic sea on the north, and the Pacific with partly the Atlantic—not South America—on the south. It is, therefore, in the best possible condition for exemplifying the law of origin of the continental features. For if the extent of the oceans is an approximate measure of the elevating forces engaged,

this open exposure to the ocean on all its sides should give the forces their best opportunity for undisturbed or regular results.

Europe, on the contrary, lies between oceans and continents, and is, therefore, complex in its rocks and mountains.

2. *Method of action, and its progress.*—The two systems of forces engaged in the progress of North America were those of the Atlantic and Pacific, the latter the greatest. Under their action the V-shaped Azoic dry land (map. page 73) was first defined, one branch stretching northeastward to Labrador and the other northwestward to the Arctic, and thus facing respectively the Atlantic and Pacific. It follows, from the courses of the arms of the V, that the Atlantic force acted mainly from the southeastward and the Pacific from the southwestward, and the two, therefore, nearly at right angles to one another. It is also apparent that the Pacific force even then was the greater, and hence the Pacific Ocean the larger; for the northwestward branch of the V is far the longer.

Thus the Azoic nucleus was outlined, and the portion of Hudson's Bay determined within the arms of the V. From this nucleal dry land, progress went forward southeastward or toward the Atlantic, and southwestward or toward the Pacific, successive formations being added under gentle oscillations, and the dry land gradually extending under changes of level caused mainly by the same forces. Then, when Paleozoic time was closing, appeared the Appalachian chain and its many ridges parallel to the *eastern* branch of the Azoic heights, and along the Rocky chain parallel to the western branch; thus doubling the V, and proving that the forces were still the same in direction as in Azoic time. The Appalachian chain follows in its direction quite closely the Azoic coast-line; for the Green Mountain portion extends north and south, like the border of the Azoic peninsula in northern New York, and then the New Jersey and

Pennsylvania portions bend around nearly to the east and west, or parallel with the southern border of the New York Azoic. South of this the chain takes again its normal direction, or from northeast to southwest. Later still, rose the trap ridges of the Mesozoic on the Atlantic border (p. 000), making another parallel to the eastern branch, or tripling the V on the east, and even repeating all the Appalachian bends just mentioned.

Again, on the Pacific side, other ranges were made parallel to the course of the Rocky Mountain chain; among them, the Sierra Nevada and Cascade range, the latter, with its many volcanoes, adding new parallels to the western branch of the Azoic. The mass of the Rocky Mountains also rose to its full height above the ocean.

Each added range, as is seen, proves that the mountain-making forces continued to act from the same directions as in Azoic time.

The intersection of effects of the Atlantic and Pacific forces may be distinguished over the interior of North America; for the courses of the uplifts of the Coal formation in Illinois and the trend of Florida are parallel to the *Pacific* border, and the line between these two intersects the Appalachian chain in eastern Tennessee. Again, there is an uplift of the Lower Silurian about Cincinnati, which appears to have been produced by the combined action of the two forces; and it is of interest to note that the Pacific and Atlantic forces here meet at a point which is four times more distant from the coast of the Pacific or *larger* ocean than it is from that of the Atlantic or *smaller* ocean.

Thus the continent made progress, adding layer after layer to the rocks over its surface, and range after range in parallel lines to its heights, until finally the continental area reached its limit, and the great interior basin had its mountain-borders completed:—on the *east*, the low Appalachians, and the trap ridges of the Mesozoic; on the *west*, the massive and lofty Rocky chain, with its parallel crests and ridges, and nearer the ocean a chain containing, north of California (in the part called the Cascade range), a number of lofty volcanic peaks, and to the south (Sierra Nevada) consisting mostly of metamorphic rocks.

It has been explained on page 234 that, when thus completed, there occurred an apparent change in the region moved by the forces. The high-latitude oscillations of the Post-tertiary began (p. 219). But the Pacific and Atlantic forces may have occasioned these new movements. For if, in the course of the changes though the geological ages, the portions of the continental crust in *lower latitudes*, thickened by the successive formations, and stiffened by mountain-chains and metamorphism, had become less yielding than those of *higher latitudes*, the pressure from contraction would have produced its oscillations in the latter rather than the former.

Thus, the evolution of the features of the surface, even to the terraces made along the river-valleys, as the era of Man opened, may have taken place through one system of forces originating in one single cause,—the earth's contraction from cooling.

CONCLUDING REMARKS.

Geology may seem to be audacious in its attempts to unveil the mysteries of creation. Yet what it reveals are only some of the methods by which the Creator has performed his will; and many deeper mysteries it leaves untouched.

It brings to view a perfect and harmonious system of life, but affords no explanation of the origin of life, or of its species, or of any of nature's forces.

It accounts for the forms of continents; but it tells nothing as to the source of that arrangement of the wide and narrow continents and wide and narrow oceans that was necessary to the grand result (p. 11).

It teaches that strata were made in many successions as the continents lay balancing near the water's level, sometimes just above the surface, sometimes a little below; but it does not explain how it happened that the amount of water was of exactly the right quantity to fill the great basin, and admit of oscillations of the land beneath or above its surface by only *small* changes of level; for if the water had been a few hundred feet below the level it now has, the continents would have remained mostly without their marine strata, and the plan of progress would have proved a failure; or if as much above its present level, the land through the earlier ages would have been sunk to depths comparatively lifeless, with no less fatal results both to the series of rocks and the system of marine and terrestrial life; and in the end there would have been broad and narrow strips of dry land and archipelagos, in place of the expanded Orient and Occident.

It may be said to have searched out the mode of development of a world. Yet it can point to no physical cause of that prophecy of Man which runs through the whole history; which was uttered by the winds and waves at their work over the sands, by the rocks in each movement of the earth's crust, and by every living thing in the long succession, until Man appeared to make the mysterious announcements intelligible. For the body of Man was not made more completely for the service of the soul, than the earth, in all its arrangements from beginning to end, for the spiritual being that was to occupy it. In Man, the bones are not merely the jointed framework of an animal, but a framework shaped throughout with reference to that erect structure which befits and can best serve Man's spiritual nature. The feet are not the clasping and climbing feet of a monkey; they are so made as to give firmness to the tread and dignity to the bearing of the being made in God's image. The hands have that fashioning of the palm, fingers, and thumb, and that delicacy of the sense of touch, which adapt them not only to feed the mouth, but to contribute to the wants of the soul and obey its promptings. The arms are not for strength alone,—for they are weaker than in many a brute,—but to give the greater power and expression to the thoughts that issue from within. The face, with its expressive features, is formed so as to respond not solely to the emotions of pleasure and pain, but to shades of sentiment and interacting sympathies the most varied, high as heaven and low as earth,—aye, lower, in debased human nature. And the whole being, body, limbs, and head, with eyes looking not towards the earth, but beyond an infinite horizon, is a majestic expression of the divine feature in Man, and of the infinitude of his aspirations.

So with the earth, Man's world-body. Its rocks were so arranged, in their formation, that they should best serve Man's purposes. The strata were subjected to metamorphism, and so crystallized, that he might be provided with the most perfect material for his art,—his statues, temples, and dwellings; at the same time, they were filled with veins, in order to supply him with gold and silver and other treasures. The rocks were also made to enclose abundant beds of coal and iron ore, that Man might have fuel for his hearths and iron for his utensils and machinery. Mountains were raised to temper hot climates, to diversify the earth's productiveness, and, pre-eminently, to gather the clouds into river-channels, thence to moisten the fields for agriculture, afford facilities for travel, and supply the world with springs and fountains.

The continents were clustered mostly in one hemisphere to bring the nations into closer union; and the two having climates and resources the best for human progress—the northern Orient and Occident—were separated by a *narrow* ocean, that the great mountains might be on the remoter borders of each, and all the declivities, plains, and rivers be turned towards one common channel of intercourse. So, also, the species of life, both of plants and animals, were appointed to administer to Man's necessities, moral as well as physical.

Besides these beneficent provisions, the forces and laws of nature were particularly adapted to Man, and Man to those laws, so that he should be able to take the oceans, rivers, and winds into his service, and even the more subtle agencies, heat, light, and electricity; and the adjustments were made with such precision that the face of the earth is actually fitted hardly less than his own to respond to his inner being:—the mountains to his sense of the sublime, the landscape, with its slopes, its trees, its flowers, to his love of the beautiful, and the thousands of living species, in their diversity, to his various emotions and sentiments. The whole world, indeed, seems to have been made almost a material manifestation, in multitudinous forms, of the elements of his own spiritual nature, that it might thereby give wings to the soul in its heavenward aspirings. It may therefore be said with truth that Man's spirit was considered in the ordering of the earth's structure as well as in that of his own body.

It is hence obvious that the earth's history, which it is the object of Geology to teach, is the true introduction to human history.

It is also certain that science, whatever it may accomplish in the discovery of causes or methods of progress, can take no steps towards setting aside a Creator. Far from such a result, it clearly proves that there has been not only an omnipotent hand to create, and to sustain physical forces in action, but an all-wise and beneficent Spirit to shape all events towards a spiritual end.

Man may well feel exalted to find that he was the final purpose when the word went forth in the beginning, LET LIGHT BE. And he may thence derive direct personal assurance that all this magnificent preparation is yet to have a higher fulfilment in a future of spiritual life. This assurance from nature may seem feeble. Yet it is at least sufficient to strengthen faith in that Book of books in which the promise of that life and "the way" are plainly set forth.

APPENDIX.

A.—Catalogue of American Localities of Fossils.

The following catalogue of American localities of fossils contains only some of the more important, and is intended for the convenience especially of the student-collector.

Localities of Fossils.

Potsdam sandstone.—Swanton, Vt.; Braintree, Mass.; Keeseville (at "High Bridge"), Alexandria, N.Y.; Chiques Ridge, Pa.; Falls of St. Croix, Osceola Mills, Trempaleau, Wisconsin; Lansing, Iowa; St. Ann's, Isle Perrot, C.W.; near Beauharnois on Lake St. Louis, C.E.

Calciferous.—Point Lévis, Mingan Islands, Philipsburg, and near Beauharnois, C.E.; Grand Trunk Railway between Brockville and Prescott, St. Ann's, Isle Perrot, C.W.; Amsterdam, Port Plain, Canajoharie, Chazy, Lafargeville, Ogdensburgh, N.Y.

Chazy limestone.—Chazy, Galway, Westport, N.Y.; Island of Montreal, C.E., (1 to 3 miles north of "the Mountain.")

Bird's-eye limestone.—Amsterdam, Little Falls, Fort Plain, Adams, Watertown, N.Y.

Black River limestone.—Watertown, N.Y.; Ottawa, C.W.; Island of Montreal, and near Quebec, C.E.

Trenton limestone.—Adams, Watertown, Boonville, Turin, Jacksonburgh, Little Falls, Lowville, Middleville, Fort Plain, Trenton Falls, N.Y.; Pine Grove, Aaronsburg, Potter's Fort, Milligan's Cove, Pa.; Highgate Springs, Vt.; Montmorency Falls and Beauport Quarries near Quebec, Island of Montreal (quarries N. of the city), C.E.; Ottawa, Belleville, Trenton (G. T. R. R., W. of Kingston), C.W.; Copper Bay, Mich.; Elkader Mills, Turkey River, Dubuque, Iowa; Falls of St. Anthony, St. Paul, Mineral Point, Cassville, Beloit, Quimby's Mills near Benton, Wis.; Warren, Illinois.

Utica slate.—Turin, Martinsburgh, Lorraine, Worth, Utica, Cold Spring, Oxtungo and Osquago Creeks near Fort Plain, Mohawk, Rouse's Point, N.Y.; Rideau River along R. R. at Ottawa, bed of river two miles above, C.W.

Hudson River group.—Pulaski, Rome, Lorraine, and Boonville, N.Y.; Penn's Valley, Milligan's Cove, Pa.; Oxford, Cincinnati, O.; Madison, Ind.; Anticosti, opposite Three Rivers, C.E.; Weston on the Humber River, nine miles W. of Toronto, C.W.; Little Makoqueta River, Iowa; Savannah, Green Bay, Wis.; Scales Mound, Ill.; Drummond's Island, Mich.

Medina sandstone.—Lockport, Lewiston, Medina, Rochester, N.Y.; Long Narrows below Lewistown, Pa.

Clinton group.—Lèwiston, Lockport, Reynolds' Basin, Brockport, Rochester, Wolcott, New Hartford, N.Y.; Thorold on Welland Canal, Hamilton, Ancaster, C.W.

Niagara.—Lewiston, Lockport, Rochester, Wolcott, N.Y.; Thorold, Hamilton, Ancaster, C.W.; Anticosti, C.E.; Arisaig, Nova Scotia; Racine, Waukesha, Wis.; Marblehead on Drummond's Island, Michigan. (*Coralline limestone.*—Schoharie, N.Y.)

Onondaga Salt Group.—Buffalo, Williamsville, Waterville, Jerusalem Hill (Herkimer co.), N.Y.

Leclaire limestone.—Leclaire, Ill.

"Galt" or "Guelph" formation.—Galt, Guelph (G. T. R. R.), C.W.

Lower Helderberg limestones.—Dry Hill, Jerusalem Hill (Herkimer co.), Sharon, East Cobleskill, Judd's Falls, Cherry Valley, Carlisle, Schoharie, Clarksville, Athens, N.Y.; Gaspé, C.E.

Oriskany sandstone.—Oriskany, Vienna, Carlisle, Schoharie, Catskill Mountains, N.Y.; Cumberland, Md.; Moorestown and Frankstown, Pa.

Cauda-Galli Grit.—Schoharie (Fucoides Cauda-Galli), N.Y.

Schoharie Grit.—Schoharie, Cherry Valley, N.Y.

Upper Helderberg limestones.—Black Rock, Buffalo, Williamsville, Lancaster, Clarence Hollow, Stafford, Le Roy, Caledonia, Mendon, Auburn, Onondaga, Cassville, Babcock's Hill, Schoharie, Cherry Valley, Clarksville, N.Y.; Port Colborne, and near Cayuga, C.W.; Columbus, Delaware, Sandusky, O.; Mackinac, Little Traverse Bay, Dundee, Monguagon, Mich.

Marcellus shales.—Lake Erie shore, ten miles S. of Buffalo, Lancaster, Alden, Avon, Leroy, Marcellus, Manlius, Cherry Valley, N.Y.

Hamilton group.—Lake Erie shore, Eighteen Mile Creek, Hamburgh, Alden, Darien, York, Moscow, Bloomfield, Bristol, Seneca Lake, Cayuga Lake, and Skaneateles Lake, Pompey, Cazenovia, Delphi, Bridgewater, Richland, Cherry Valley, Seward, Westford, Milford, Portlandville, N.Y.; Widden Station (G. T. R. R.), near Port Sarnia, C.W.; New Buffalo, Independence, Iowa; Rock Island, Ill.; Thunder Bay, Little Traverse Bay, Mich.; Nictaux, Bear River, Moose River, Nova Scotia.

Genesee slate.—Banks of Seneca and Cayuga Lakes, Lodi Falls, Mount Morris, two miles S. of Big Stream Point, Yates co., N.Y.

Portage group.—Eighteen Mile Creek, Lake Erie shore, Chautauqua Lake, Genesee River at Portage, Flint Creek, Cashaqua Creek, Nunda, Seneca and Cayuga Lakes, N.Y.

Chemung group.—Rockville, Philipsburgh, Jasper, Greene, Chemung Narrows, Troopsville, Elmira, Ithaca, Waverly, Hector, Enfield, N.Y.; Gaspé, C.E.

Catskill group.—Fossils rare.—Richmond's quarry above Mt. Upton on the Unadilla, Oneonta, Oxford, Steuben co. south of the Canisteo, N.Y.; Blossburg, Pa.; Pompton, Old Boonton, Pluckamin, N.J.

Subcarboniferous.—Burlington, Keokuk, Iowa; Quincy, Warsaw, Alton, Kaskaskia, Chester, Ill.; Bloomington, Spergen Hill, Ind.; Hannibal, St. Genevieve, St. Louis, Mo.; Willow Creek, Battle Creek, Holland, Grand Rapids, Mich.; Mauch Chunk, Pa.; Red Sulphur Springs, Pittsburg Landing, Tenn.; Big Bear and Little Bear Creeks, Big Crippled Deer Creek, Miss.; Clarksville, Huntsville, Ala.; Windsor, Horton, Nova Scotia.

Carboniferous.—South Joggins, Pictou, Sydney, Nova Scotia; Wilkesbarre, Shamokin, Tamaqua, Pottsville, Minersville, Tremont, Greensburg, Carbondale, Port Carbon, Lehigh, Trevorton, Johnstown, Pittsburg, Pa.; Pomeroy, Marietta, Zanesville, Cuyahoga Falls, Athens, Ohio; Charlestown, Clarksburg, Kanawha Salines, Wheeling, Va.; Saline Company's mines, Gallatin co., Terre Haute, Morris, Springfield, Ill.: Bell's, Casey's, and Union Mines, Crittenden co.; Hawesville and Lewisport, Hancock co.; Breckinridge, Giger's Hill, Mulford's Mines, and Thompson's Mine, Union co.; Providence and Madisonville, Hopkins co.; Bonharbour, Daviess co., Ky.: Muscatine, Alpine Dam, Iowa; Leavenworth, Indian Creek, Grasshopper Creek, Juniata, Manhattan, Kansas.

Triassic.—Southbury, Middlefield, Portland, Conn.; Turner's Falls, Sunderland, Mass.; Phœnixville, Pa.; Richmond, Va.; Deep River and Dan River coal-fields, N.C.

Cretaceous.—Upper Freehold, Middletown, Marlboro', Blue Ball, Deal, Squankum, Shark River, Monmouth co.; Pemberton, Vincenton, Burlington co.; Blackwoodtown, Camden co.; Mullica Hill, Gloucester co.; Woodstown, Mannington, Salem co.; New Egypt, Ocean co., N.J.: Warren's Mill, Itawamba co.; Tishomingo Creek, R. R. cuts, Hare's Mill, Carrollsville, Tishomingo co.; Plymouth Bluff, Lowndes co.; Chawalla Station (M. & C. R. R.), Ripley, Tippah co.; Noxubee, Macon, Noxubee co.; Kemper, Pontotoc and Chickasaw counties, Miss.: Tuscaloosa, Ala.: Fox Hills, Sage Creek, Long Lake, Great Bend, Cheyenne River, etc., Nebraska.

Eocene.—Everywhere in Tippah co.: Yockeney River, New Prospect P. O., Winston co.; Marion, Lauderdale co.; Enterprise, Clarke co.; Jackson; Satartia, Yazoo co.; Homewood, Scott co.; Chickasawhay River, Clarke co.; Winchester, Red Bluff Station, Wayne co.; Vicksburg, Amsterdam, Brownsville, Warren co.; Brandon, Byram Station, Rankin co.; Paulding, Jasper co., Miss.: Claiborne, Monroe co.; St. Stephen's, Washington co., Ala.: Charleston, S.C.; Tampa Bay, Florida; Fort Washington, Fort Marlborough, Piscataway, Md.; Marlbourne, Va.; Brandon, Vt.; Cañada de las Uvas, Cal.

Miocene.—Gay Head, Martha's Vineyard, Mass.; Shiloh, Jericho, Cumberland co., N.J.; St. Mary's, Easton, Md.; Yorktown, Suffolk, Smithfield, Richmond, Petersburg, Va.; Astoria, Willamette River, Oregon; San Pablo Bay, Ocoya Creek, San Diego, Monterey, San Joaquin and Tulare Valleys, Cal.; White River, Upper Missouri Region.

Pliocene.—Ashley and Santee Rivers, S.C.; Platte and Niobrara Rivers, Upper Missouri.

B.—Geological Implements, Specimens, etc.

1. Implements.—The student requires for his geological excursions and research the following implements:—

(1.) A hammer of the form in fig. 373. The face should be flat, and nearly square, with its edges sharp instead of rounded. The socket for the handle should be large, that the handle may be strong. The hammer, for ordinary excursions, should weigh 1½ pounds exclusive of the handle; the handle should be about 12 inches long. Another is required for trimming specimens, weighing half a pound.

Fig. 373.

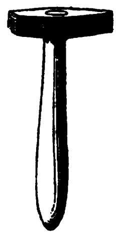


Fig. 374.

(2.) A *hammer* in the form of a small pick, like fig. 374, for picking open the layers of slaty rocks, etc. It should be 7 or 8 inches long, and terminate above in a chisel-like edge transverse to the handle. The length of handle may be 13 or 14 inches.

(3.) A *steel chisel,* 6 inches long, 1 inch wide at top, and tapering to a narrow edge, or wedge-shaped. Also, another half of these dimensions.

(4.) A *clinometer*, with *magnetic needle* attached. See page 40. The best kind is a pocket instrument in the form of a watch, about 2½ inches in diameter.

(5.) A *small magnet.* A magnetized blade of a pocket-knife is a good substitute.

(6.) A *measuring-tape* 50 feet long. The field geologist should know accurately the measurements of his own body, his height, length of limbs, step or pace, that he may use himself, whenever needed, as a measuring-rod.

(7.) In many cases, a *pick,* a *crow-bar,* a *sledge-hammer* of 4 to 8 pounds' weight, and the means of blasting, are necessary.

(8.) A *strong sack-coat,* with very large and stoutly made side-pockets.

(9.) Besides the above, a *barometer* and *surveyor's instruments* are occasionally required. Of the latter, a *hand-level* is a very desirable instrument for determining small elevations by levelling. It is a simple brass tube, with cross-hairs, bubble and mirror.

2. **Specimens.**—Specimens for illustrating the kinds of rocks should be carefully trimmed by chipping to a uniform size, previously determined upon: 3 inches by 4 across, and 1 inch through, is the size commonly adopted. In the best collections of rocks, the angles are squared and the edges made straight with great precision. They should have a fresh surface of fracture, with no bruises by the hammer. It is often well to leave one side in its natural weathered state, to show the effects of weathering.

Specimens of fossils will, of course, vary in size with the nature of the fossil. When possible, the fossil should be separated from the rock; but this must be done with precaution, lest it be broken in the process, and should not be attempted unless the chances are strongly in favor of securing the specimen entire. The skilful use of a small chisel and hammer will often expose to view nearly all of a fossil when it is not best wholly to detach it. When the fossils in a limestone are silicified (a fact easily proved by their scratching glass readily and their undergoing no change in heated acid), they may be cleaned by putting them into an acid, and also applying heat very gently, if effervescence does not take place without it. The best acid is chlorohydric (muriatic) diluted one-half with water.

Collections both of rocks and fossils should always be made from rocks *in place*, and not from stray boulders of uncertain locality.

3. **Packing.**—For packing, each specimen should be enveloped separately in two or three thicknesses of strong wrapping-paper. This is best done by cutting the paper of such a size that when folded around the specimen the ends will project two inches (more or less, according to the size of the specimen); after folding the paper around it, turn in the projecting ends (as the end of the finger of a glove may be turned in), and the envelop will need no other securing. Pack in a strong box, pressing each specimen, after thus enveloping it, firmly into its place, crowding wads of paper between them wherever possible, and make the box absolutely full to the very top (by packing-material if the specimens do not suffice), so that no amount of rough usage by wagon or cars on a journey of a thousand miles would cause the least movement inside.

4. **Labelling.**—A *label* should be put inside of each envelop, separated from the specimen by a thickness or more of the paper. The label should give the precise locality of the specimen, and the particular stratum from which taken, if there is a series of strata at the place; it should also have a number on it corresponding to a number in a note-book, where fuller notes of each are kept, together with the details of stratification, dip, and strike, sections, plans, changes or variations in the rocks, and all geological observations that may be made in the region. A specimen of rock or fossil of unknown or uncertain locality is of very little value.

5. **Note-Book.**—The note-book should have a stiff leather cover, and be made of rather thick smooth writing-paper, good for sketching as well as for writing. Five inches by three and a half is a convenient size. A kind made of prepared paper, and provided with a zinc-pointed pencil, is often sold for the purpose, and is excellent until it gets perchance a fall into the water, when the notes that may have been carefully made will be pretty surely obliterated. If the geologist is a draftsman, he may also need a portfolio for carrying larger paper; but the small note-book will, in general, answer every purpose.

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Note.—The asterisk after the number of a page indicates that the subject referred to is illustrated by a figure.